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REPORT OF THE NATIONAL COMMISSION ON SPACE

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BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

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ON

Report of the National Commission on Space

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REPORT OF THE NATIONAL COMMISSION ON SPACE

TUESDAY, JULY 22, 1986

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY AND SPACE,
Washington, D.C.

The subcommittee met, pursuant to notice, at 2:33 p.m. in Room SD-628, Dirksen Senate Office Building, Hon. Slade Gorton (Chairman of the subcommittee) presiding.

Staff members assigned to this hearing: Pete Perkins, professional staff member and Marty Kress, minority professional staff member.

OPENING STATEMENT BY SENATOR GORTON

Senator GORTON. I am delighted to convene this hearing on the Subcommittee of Science, Technology, and Space to consider the report of the National Commission on Space and the Commission's proposed agenda for our civilian space program for the next 20 years and beyond. Nearly two years have passed since Congress enacted legislation establishing the National Commission on Space, and we have been understandably anxious to review the results of the Commission's efforts.

First, I want to congratulate the Chairman of the Commission, Dr. Tom Paine, the other members of the Commission, and their staff for their dedicated service over the course of the past year. They took on a difficult task, one which required them to contemplate not only the future of our space program, but also the future of the United States. In doing so, the Commissioners and staff traveled hundreds, if not thousands, of miles back and forth across the country and talked to and listened to hundreds of citizens who are concerned about the future of our civilian space program. To summarize the results of this year-long effort into the report before us is a noteworthy accomplishment in and of itself.

Moreover, this report not only provides the nation and our space program with an extremely useful resource, but it also is a testimony to the sacrifice and commitment of each Commissioner and of the staff. For this we owe all of you a debt of gratitude.

Regrettably, we are unable to consider the report in an environment that is free from the weight of recovering from the most tragic event in the history of our space program. NASA and those of us in Congress who are responsible for oversight of our space program are presently consumed with the tasks of correcting both technical and management related problems.

Just as difficult are the problems associated with funding these corrective measures, while at the same time attempting to maintain progress in NASA's ongoing programs, all within the most austere budgetary environment we have faced in years. This effort is further complicated and aggravated by the inexcusable delay of the administration in developing an appropriate space recovery plan in a timely fashion. Certainly this is an unfair environment in which to consider this Commission's report.

Nevertheless, within the realities of the budgetary and political processes, we should take advantage of the tremendous amount of work that this report represents. The goals established in this report are bold and visionary, just as Congress requested. It is now the responsibility of the administration and the Congress to assess the recommendations of the Commission. Some of these recommendations may ultimately be deemed inappropriate for one reason or another. Others may be outside the scope of our national funding capability. Nevertheless, I believe that we will ultimately achieve many of the goals proposed by the report.

Certainly, we should not get caught up in the trap of creating unreasonable expectations, or expecting too much too soon. Failure to meet artificial deadlines can give the skeptics ammunition to point to shortfalls between rhetoric and performance. But for those of us here today who are understandably impatient to continue the aggressive exploration of this next frontier, the report should stimulate the debate on the future of our space program and help focus our nation's efforts.

Senator Hollings, do you have an opening statement?

OPENING STATEMENT BY SENATOR HOLLINGS

Senator HOLLINGS. Thank you, Mr. Chairman.

Mr. Chairman, 3 years ago when I introduced the bill to create the National Commission on Space, I must admit that never did I think such a fine product would evolve.

On this very special day for you, Dr. Paine, the Members of the Commission and the staff, I would like to compliment each and every one of you for a job well done. "Pioneering the Space Frontier" is a valuable document. I am hopeful that it will reactivate the support of the American public for space exploration as well as captivate the minds of America's youth. I also am hopeful that President Reagan will strongly endorse your findings and recommendations this afternoon.

During these most difficult days for the civilian space program, it is nice to be handed a blueprint for the future and to be reminded of the challenges that lie ahead. In the aftermath of the *Challenger* disaster, the future of the space program has been too narrowly defined as the restoration of our launch capabilities. Your report reminds the

American public and the Congress that we have just begun our exploration of space. The challenges that lie ahead, the discoveries that remain to be made, and the missions that remain to be flown are the stuff that dreams are made of. You have reminded all of us that a "man's reach should far exceed his grasp," and you are to be complimented.

Now that you have given us the blueprint for the future, it is up to the Congress and the White House to discuss its merits and to make the necessary investment. Hopefully, if this Nation remains committed to the space program and space exploration, our youth will retain their interest in the fields of science, mathematics and engineering; and the U.S. will retain its technological leadership. However, I must be honest. The degree of resolve that currently exists for the space program pales in comparison with the level of support for the Apollo program. If we are to proceed with a well-balanced, visionary space program, it will take a firm base of support—political, budgetary and popular support—and prioritization of the civilian space program in future budgets.

I should indicate that I was particularly pleased that your report stressed the importance of adequate funding of advanced technology development and the need for an effective space policy decisionmaking apparatus. As an original co-sponsor of S. 2473, a bill to reestablish the National Aeronautics and Space Council, I couldn't agree with you more. I also am hopeful that your emphasis upon advanced technology development will help convince the Congress to increase funding for these activities in fiscal year 1987. Too often when confronted with budget constraints, the Congress eliminates the seed corn of the future. Hopefully, this Congress will recognize the value of advanced technology development in this year's NASA authorization and manifest the priority status of these activities.

Finally, let me say that I am most grateful for the service rendered by the Commission, its members and staff. The affects of the events of January 28 upon the civilian space program, U.S. technological leadership in space, and your report could not have been foreseen at the time the legislation creating the Commission was passed. Your effort to incorporate the consequences of the shuttle disaster in your findings and recommendations is much appreciated.

I look forward to your testimony and to a lively panel discussion with Dr. Van Allen and Dr. Donahue.

Hopefully, today's discussion will be the first of many concerning the future scope, direction and emphasis of the U.S. civilian space program.

Thank you, Mr. Chairman.

Senator GORTON. With these thoughts in mind, we are fortunate to have with us today five members of the Commission, Dr. Tom Paine, Dr. Laurel Wilkening, Dr. George Field, Dr. Jack Kerrebrock and Dr. Kathryn Sullivan, in addition to Dr. Tom Donahue of the National Academy of Sciences and Dr. Jim Van Allen of the University of Iowa. Each of these distinguished individuals should contribute significantly to today's discussion of our nation's future involvement in space, and the subcommittee looks forward to their counsel and advice.

And with that, of course, Dr. Paine, we will start with you, and we will be delighted to hear from you.

STATEMENT OF DR. THOMAS O. PAINE, CHAIRMAN, NATIONAL COMMISSION ON SPACE; ACCOMPANIED BY DR. LAUREL L. WILKENING, VICE CHAIRMAN; DR. GEORGE B. FIELD; DR. JACK L. KERREBROCK; AND DR. KATHRYN D. SULLIVAN, MEMBERS

Dr. PAINE. Thank you, Mr. Chairman.

I would like to open by thanking this committee on behalf of all of the members of the Commission, both the Commissioners and the staff, for the opportunity that you gave us to address these very difficult questions over the course of the past year.

We have had, of course, the tragedy of the *Challenger* in the midst of our deliberations, but I think in many ways perhaps as the nation pauses to regroup and rebuild our launch vehicle capability and reorganize NASA to strengthen it even further for the future, that this probably represents a very good time to take a look at the long range future of the American space program, and I think that your foresight in asking us to do this more than a year ago is certainly repaid by the chance today to take a good solid look at where we are going in space.

In many ways the Commission has served as the eyes and ears of this committee, perhaps. We have, as you pointed out, been across the length and breadth of the country, remote areas like Seattle, and we have also been even farther west, to Hawaii. We have been in the south to Florida, up to Boston, and through the middle part of the country, asking the experts in each place, but also soliciting from private citizens their views on the place of the space program in American society, where they would like to see the United States go in space, and we found it a very inspiring experience.

My own feeling about this is that in many ways the people of this country have run ahead of their leaders in Washington. I think we are indeed faced to some extent with a crisis of direction and pace, and we hope very much that our report will provoke a lively discussion that will allow people to focus on this question of where the United States should be going in space.

As you may know, Mr. Chairman, at the conclusion of this hearing we will be presenting our report to the President, if things go according to schedule, and this morning we appeared before the House committee. So today, July 22, constitutes the formal turning over of our findings to the Senate and the House and to the President.

I think it is not too much to say that more than a new launch vehicle or a replacement orbiter or a space station and perhaps even more important than an increased budget, the thing that NASA needs the most today is a new sense of purpose and new long range goals. Aimlessness and indecision are going to devastate our civilian space program. The crucial decisions that we need about next generation launch vehicles, about replacement orbiters, about the mix of manned and unmanned missions, about the mix of private and government investment—these

questions must be addressed, and all of these questions have an inordinate effect on other parts of our space program. The whole question of the future of our planetary exploration, our basic research, our fundamental science and space program, is being inordinately impacted by questions of what will be the funding.

So in a sense we meet at a very good time; I think a very timely review is certainly in order. And I believe that without high level vision and purpose and leadership, essentially we will have no future in space.

But nevertheless, we are convinced that the exploration of outer space and American leadership in this area is something that the American people overwhelmingly endorse. I think it is more a question of how to go about it, what level of funding is appropriate. These are the things that need to be addressed.

I would like to ask my associates, Dr. Laurel Wilkening and Dr. George Field, to make a short opening statement, after which we would like to make ourselves available for your questions.

And with your permission I will put a somewhat longer introductory statement into the record.

Senator GORTON. It will be included in the record as if read.

[The statement follows:]

STATEMENT OF DR. THOMAS O. PAINE, CHAIRMAN, NATIONAL COMMISSION ON SPACE

AMERICA'S FUTURE IN SPACE

As NASA pauses to rebuild in the wake of the Challenger disaster, it is time for a thoughtful, high-level of America's future in space. Throughout this country and, indeed, around the world, people are looking to the President and the Congress to reaffirm the rationale, direction and pace of our civilian space program. NASA urgently needs a new sense of purpose and long-range objectives. Where is our space program headed? What goals lie beyond the Space and low Earth orbit? What future space agenda will best further the broader objectives of 21st-century America? What are humanity's overarching goals in space?

In 1984 the National Commission on Space was charged by the Congress and appointed by the President to address these questions. We have looked 50 years into the future, and are proposing bold civilian space goals for the next 20 years. We have completed our work and submitted to your staff and to the White House staff our final report, *Pioneering the Space Frontier*. To facilitate public discussion of the complex issues involved, we are making the report widely available at bookstores across the country through Bantam Books. This "Gutenberg" version has been supplemented by a 30-minute TV tape report that is also available to the media and the public; we are holding its world premier in our hearings today.

In conducting the studies leading to the preparation of its final report, the Commission took testimony from expert witnesses in meetings across the country, received opinions from hundreds of citizens the public forums, commissioned studies of future technological progress by the American Institute of Aeronautics and Astronautics (AIAA), convened a meeting of futurists to consider 21st-century America, sponsored an AIAA symposium on space commercialization, initiated a review of two centuries of U.S. and world economic growth, and solicited suggestions through periodicals, direct mail and electronic bulletin boards. In Paris and Bonn a few of us reviewed the European Space Agency's new interest in commercial enterprise and manned space flight. In Moscow we discussed opportunities for joint Soviet-American space missions, and the new Soviet concentration on Mars, including their scheduled 1988 robotic mission to explore the Martian moons, Phobos and Deimos. From all of these activities a vision of the next 50 years in space emerged that provided the basis for our Commission's conclusions and recommendations.

We see advancing space technologies freeing mankind to move outward from Earth as a species destined to expand to new worlds. America's pioneering heritage, technologies preeminence and economic strength make it fitting that this Nation lead mankind's movement into the Solar System. As formerly on the western frontier, now on the space frontier government should support initial exploration and science, advance critical technologies, and provide the basic transportation infrastructure, legal framework and civil administration required to open broad access to new lands. Such a future-oriented investment by the American people will again generate in value many times its cost, to the benefit of future generations.

With this rationale in mind, the Commission proposes this broad, long-range, pioneering mission for the American space program:

To lead the exploration and development of the space frontier, advancing science, technology and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars.

To accomplish this mission, three mutually-supportive thrusts are outlined:

Advancing scientific understanding of Planet Earth, the Solar System and the Universe;

Exploring, prospecting and settling the Solar System; and

Stimulating space enterprise.

To support these, two additional thrusts are essential:

Advancing technologies across a broad spectrum to enhance capabilities and lower costs; and

Creating systems and institutions to provide safe, reliable, low-cost access to the space frontier

These thrusts will involve a creative partnership of government, academia and industry of the type which has proven so effective in our history. Our most urgent need, and the greatest contribution NASA can make by the year 2000, is to lower by an order of magnitude the cost of transporting cargo and passengers into orbit and beyond throughout the inner Solar System. Critical technologies include dual-cycle rocket engines, aerospace plane systems, artificial intelligence, tethers, advanced materials and aerobraking systems. To "live off the land" on the space frontier,

NASA must vigorously pursue two new technologies: robotic processing of extraterrestial materials, and closed-ecology biospheres to recycle air, water and food. All of these technologies have major implications for 21st-century America's economic strength and security.

Our proposed 20-year civilian space goals include a "Highway to Space" and "Bridge Between Worlds." These will support initial astronaut outposts on the Moon by 2005. A decade later spaceships with artificial gravity can begin to cycle between the orbits of Earth and Mars to open continuous human access to the rich resoures and spectacular landscapes of Mars. The Commission's proposed new space agenda for America is paced to maintain NASA's budget at less than half the peak percentage of national expenditures reached during the Apollo years. The expected benefits to America and the world will greatly outweigh the costs. Major international participation is proposed in a program that the Commission is confident will attract the best minds of the 21st century.

Our report recognizes that the final decision wil be made by the American people through the Congress and the Administration. The Commission report is therefore not a prophesy, but a description of what the United States can make happen through vigorous leadership in pioneering the space frontier.

More than a new launch vehicle, more than a replacement orbiter or space station—even more than an increased budget—NASA needs a new sense of purpose and new long-range goals. Aimlessness and indecision will devastate America's civilian space program. Crucial decisions about future launch vehicles, shuttle orbiters, the space station, space science and technology programs, and budget levels must be addressed in a timely fashion. Without high-level vision, purpose and leadership, there can be no future for America in space.

The exploration of the Moon and Mars with robotic precursors followed by continuing human presence, is a sound, long-range goal. It would restore NASA's vigor and attract top people to the space program. Such a goal would define a purpose for the space station, so that its requirements, design and schedule could be sensibly planned. It would provide a basis for international contribution and participation. It would provide a focus for planetary exploration and guide supporting missions of science and technology. It would support the development of a logical launch vehicle plan, involving the private sector, with the best mix of piloted and automatic vehicles. It would reorient our space program to serve America's broader national interests and security. If the United States and the Soviet Union can find ways to join together to lead humankind to new worlds, we can develop new opportunities for harmony and peace on Earth. Creating a bridge to the Moon and Mars will give human space flight its greatest role: exploring the unknown to open new worlds for future generations.

Senator GORTON. Dr. Wilkening.

Dr. WILKENING. Yes, I will also submit a longer statement, but I will go briefly over the points that I want to stress.

Senator GORTON. Without objection, it will be included in its entirety.

Dr. WILKENING. Thank you.

Mr. Chairman, Senator Hollings, and ladies and gentlemen, we do appreciate the opportunity to participate in your discussion of the future of the civilian space program today. In our review of the civilian space program, the Commission identified three major areas in which the U.S. civilian space program could provide world leadership and thereby obtain a substantial return for our investment in those areas. They are science, exploration, and space enterprise.

Today I will direct my remarks primarily to exploration, that is, exploring, prospecting and settling the inner solar system. The Commission's view is that we are poised on the boundary of the space frontier. Our scouts, mostly robots, have traveled far and wide in the new territory, the solar system. Regular human expeditions are now visiting the first outposts in earth orbit. The exploration of the inner

solar system, that is, our planetary neighbors, Venus, Mars and the Moon, have gone far beyond mere reconnaissance. Indeed, even a human geologist has visited the Moon and conducted various scientific studies there, some of which could be characterized as real prospecting.

In the case of Mars, very sophisticated sets of robotic spacecraft, the Mariners and the Vikings, probed its atmosphere and surface. The Vikings provided detailed photography of very interesting areas on the surface of Mars.

In the case of Venus, the Soviet Union as well as the United States in separate missions have provided substantial information about the Venus atmosphere and surface.

The work of these frontier pathfinders is complete. The inner solar system is now ready for the prospectors and entrepreneurs. The question now before us is what will be the role of the United States? Our choices are simple. Either we lead, follow or drop out.

In contrast to the first decade and a half of the space age when the U.S. was the acknowledged leader in space science and exploration, the situation today in the mid-1980s is quite different. There is no longer a lack of activity by other countries. If the United States is going to lead, we cannot proceed at our own leisurely pace.

The importance of space is recognized now worldwide, and the pace of space activity on a world scale has accelerated greatly just in the last five years.

This past year has seen the encounter of Comet Halley by spacecraft from the countries represented in the European Space Agency, the Soviet Union and Japan, and not the United States. The European Space Agency has announced a long range plan for returning a sample from a comet. The Soviet Union has announced a series of increasingly ambitious missions focused on Mars, including a lander which will hop around on the surface of one of its moons making chemical assays there. They are also planning a mission to involve the study of several asteroids, including the large bright asteroid Vesta.

On the other hand, as you are well aware, the most recent planetary mission launched by the United States was Pioneer Venus in 1978, and while NASA has a plan for a series of missions to continue our leadership in solar system exploration, that plan is grounded due to the lack of availability of a suitable launch vehicle since the cancellation of the Centaur upper stage.

The Galileo mission to Jupiter, the first planetary mission mounted by the United States since 1978, which was ready for launch this summer, is grounded indefinitely.

Far from taking the steps that are necessary to bring about a major enhancement of scientific activities undertaken by this nation for the next decade, we are doing quite the opposite. No new science missions are being considered by NASA at this time, no plan seems to be developing for deep space launch capability, and tremendous uncertainty surrounds the future of the replacement of the space shuttle *Challenger*.

Rather than planning for continued leadership in space science, a lack of commitment by this nation to the civilian space program is resulting in a rapid erosion of our space science programs from life sciences to astrophysics.

The Commission believes that space science and exploration are too important to the United States to be abandoned, but by default we are abandoning them.

What should we be doing? The National Academy of Sciences and the various scientific advisory committees to NASA have carefully and thoughtfully designed plans for space sciences in the future. The Commission endorses those plans.

Thus, detailed planning has occurred in those areas of the space program that relate to prospecting, resource development, and industrialization. We know from our scientific studies that Venus is a very inhospitable planet. The surface temperature is high enough to melt lead. For this reason, in our Commission reports we have excluded Venus as a long term prospect for robotic and human exploration.

On the other hand, the Moon and Mars, while they provide their own particularly difficult environments, do hold out the possibility that extended scientific and eventual commercial activity could take place on one or both of these objects. For this reason our plans are focused on the Moon and Mars.

We have found that in the near term there is a certain amount of overlap between the types of activities that are aimed at industrialization in space and purely scientific exploration. For example, for both scientific reasons and for prospecting we would recommend that a robotic lunar prospector mission be undertaken to examine the entire surface of the Moon from low orbit. Another example would be the study of asteroids, earth and space-based searches for readily accessible asteroids, and telescopic characterization of them followed by robotic exploration.

A similar series of robotic prospecting missions for Mars could also be described. Those studies seem to culminate in the return of samples from locales on Mars showing promise for future human activity as well as scientific interest.

We have made some big assumptions in our Commission work. We made those assumption by looking at analogies with past frontiers and past human exploration, and we assumed that exploration and prospecting would lead to space-based commerce. As economic activity develops in the inner solar system, we also assumed that humans would follow, just as the settling of our western frontier followed the economic activity associated with mining and farming on the Pacific coast.

This country needs a national commitment to a civilian space program. Technologically we are so close, politically we are so far away. What is lacking is the commitment. This commitment must focus on specific goals.

On the assumptions that I have stated, bold assumptions, we recommended a 50 year goal of establishing bases on the Moon and Mars. Such a long term goal would allow the development of an orderly plan

that would result in a lasting presence rather than a one shot space spectacular. It is the difference between Scott and Amundsen's dashes to the South Pole and the building of the Alaskan Pipeline. The time has come for humans to move into space with the expectation of living and working there.

The only question is what language will those people be speaking?

Thank you, MR. Chairman.

Senator GORTON. Thank you, Doctor.

Dr. Field?

Dr. FIELD. Thank you, Mr. Chairman. I will be very brief.

I also have a statement. If you would allow me, I would like to submit it for the record.

Senator GORTON. It will be so included.

Dr. FIELD. I would just like to underline what the Chairman and the Vice Chairman of our Commission have said, and stress that I find it very inspiring that a national commission, conceived and chartered by the Congress and appointed by the President of the United States, has come out with a very specific, long range goal for our space program.

As the previous speakers have stated, I strongly feel that such a long range goal is critical, and I think that particularly in the present context we will find the setting of such a goal a way to clarify all of the issues that face us at the present time.

Putting it in a nutshell, our goal is to begin the expansion of civilization into space.

That to many seems visionary. The Commissioners I think very quickly recognized that they personally had had some level of commitment to this kind of activity for the future of our country and for the world. Yet as we pondered this question, we sought to find a rationale which would undergird that, and in the report we tried to develop such a rationale, that would give a reason or an explanation or a glimpse of understanding as to why and how civilization will move into space.

So I recommend that to you, and I hope that as you develop legislation following on this report that you will take into account our attempt and improve upon it.

Let me also comment briefly on the space science part of the program. I am very pleased, as has been already expressed by Dr. Wilkening, that there is a strong emphasis on scientific discovery and exploration in the report. The Commission was very fortunate in having the informal advice of the National Academy of Sciences. I think Dr. Donahue will speak to that later. But personally, I am proud of the scientific goals which are established in the report. And so I am proud in general to have been associated with this endeavor, and I hope very much that the Congress will find it useful as it tries to develop future space goals.

[The statement follows:]

STATEMENT OF DR. GEORGE FIELD, MEMBER, NATIONAL COMMISSION ON SPACE

I am honored to testify as a member of the National Commission on Space. I urge the Congress to begin a critical reexamination of our goals in space, and to give serious consideration to the goals recommended by the Commission.

As an astronomer, I am delighted that the Commission assigned high priority to the advancement of science. The achievements of our space science program have laid the basis for an exiting program in the future. The program described in the Commission Report, which benefited greatly from preliminary findings of a study now being completed by the Space Science Board, is aimed at understanding the evolutionary processes in the Universe that define its present characteristics, and at applying the new understanding to forecasting future phenomena, particularly those which impact human life.

Those program will address questions at the frontiers of science, including the basic laws of physics, the evolution of matter in the Universe, the origin and evolution of the Solar System, the behavior of plasmas in the Sun and the space around it, the origin and evolution of life, and research on materials and living organisms in microgravity. A "mission to planet Earth" will monitor changes in the Earth, its oceans and its atmosphere, and by achieving a deeper understanding of the Earth, it will enable prediction of changes that will affect human activities. The space science program recommended by the Commission will integrate the findings of diverse scientific disciplines into a more unified understanding of the Universe and our place in it.

The Space Act of 1958 authorizes NASA to carry out activities in a number of different areas. In the light of subsequent experience, more specific goals should now be set by Congress. I strongly believe that America should pioneer the space frontier. A single challenging long-range goal should be adopted in order to mobilize our resources and our creativity. The Commission's Mission Statement on page 2 of the Report meets this requirement.

Human settlement of bodies beyond the Earth is such a demanding goal that it will succeed only if it is in harmony with the basic values and aspirations of the American people. Is it? The Commission deals with this question in the section entitled "Rationale for Exploring and Settling the Solar System" on page 3, and concludes that the answer is affirmative. I recommend that in framing legislation which will set new goals in space Congress should consider this question seriously.

The Commission recognizes that both manned and unmanned missions are necessary to achieve a cost-effective program. I believe that as detailed plans are developed, the objective of advancing science most cost-effectively can serve an important role in helping to decide when and how to use people in space. Some scientific activities, such as reconnaissance and mapping of planets and other bodies, can be achieved at lower cost without using people in space. Others, such as the maintenance of complex facilities in Earth orbit, require people. As our scientific frontiers expand, people will be required to staff bases on the Moon and Mars. Once our scientific objectives are established, the proper mix of manned and unmanned missions can be chosen so as to minimize cost.

America should pioneer the space frontier peacefully and in hopes of increased world cooperation as recommended in the Report. In so doing, we will direct our energies not toward building new weapons, but toward building a new civilization. This task, requiring the courage, ingenuity and perseverance demonstrated by our pioneer ancestors, is one worthy of America.

Senator GORTON. Thank you.

Dr. Paine, do either of the other members of the Commission wish to make a statement?

Dr. PAINE. Yes, Dr. Kerrebrock.

Dr. KERREBROCK. Yes, maybe, just very briefly.

Mr. Chairman, Senator Hollings, I speak for the Commission on the need for an expanded, more stable, more aggressive program of research and technology in support of our nation's space program. This is a feeling which the Commission holds unanimously, I believe, and very strongly, that the United States must increase its commitment to the base technology programs if it is to retain leadership in space.

These programs are presently at a level of effort which is about one-third of what they were during the peak of the U.S. space effort from 1965 to 1970, and in our judgment, not sufficient to meet the needs of the nation's future space program, nor to attract in full measure the best and brightest talent of the United States to these programs.

So we have recommended in our report that the level of effort of the base technology programs be increased by about a factor of three, the NASA program, that is, and that furthermore, a set of seven critical technologies be advanced by technology validations to the point where they can be selected for operational programs, space science missions or other things if that becomes appropriate.

Now, I would like to just say a couple of words about the distinction between those two kinds of technology programs that I mentioned. One is the broad base technology program which is supported as a single line item in NASA's budget, which presently is about $170 million. This is the funding line from which NASA supports the work on space technology in its laboratories and its contractual and grant work with universities, research laboratories and industry. It is to be viewed as the opportunity-generating mechanism for the nation's future in space, to the extent that the opportunities are technologically limited. It produces ideas, develops those ideas to the point where they could be selected for more vigorous prosecution in these technology validation programs such as I mentioned.

Now, I would like to say that I recognize that it has always been difficult for administrations and for the Congress to decide how much is enough in support of this kind of activity because it does not have a schedule, necessarily so, because one does not know in detail what one is going to do with it.

The question arises, why not stretch it out? Why do we have to do it now? Why not next year? Well, I want to give you two answers to that. One is that delay in such activities will surely lead to missed opportunities. Those opportunities may be missed by everyone, or they may be picked up by other nations and pursued outside the United States.

Another answer I could give you is that I think the level of support in such activities should be high enough to ensure that we make optimum use of the talents which are the most precious resource that we have in the United States, the talents that are dedicated to working in the space program, particularly those young people who are in their formative stages.

Now, in the final analysis, though, it comes down to a question of judgment, how much is enough. And I say it is the consensual judgment of the Commission that this factor of three is about right.

I will stop with that.

[The statement follows:]

STATEMENT OF DR. JACK L. KERREBROCK, MEMBER, NATIONAL COMMISSION ON SPACE

Mr. Chairman, Ladies and Gentlemen, my subject today is the Nation's need for an expanded, more stable, and more aggressive program of research and technology development in those areas which are critical to our continued leadership in space. The United States must substantially increase its investment in space technology if it is to retain leadership in the scientific and commercial uses of space, in the face of strong challenges from abroad. In financial terms, the current level of effort in Space Research and Technology supported by NASA is less than one-third that of the period from 1965 to 1970, when the U.S. was making such great strides in space. With the exception of those special areas augmented by the Strategic Defense Initiative, this shortfall has not been made up by other sources of support. In personal terms, we must renew the Nation's commitment to advancement of the intellectual frontiers of space if we are to expect adequate numbers of the Nation's brightest and most creative young people to make their careers in space, as many did in the earlier era.

The research and technology efforts which must be supported fall in two classes, those characterized as components of the Research and Technology Base, and those which are classified as technology validation or technology demonstration. The Commission recommends a factor of three increase in the NASA Space Research and Technology Program which supports a significant part of our space technology work, including most of that done in universities. It also recommends intensified technology validation efforts in seven technologies judged critical to our future in space. I wish to spend a few moments clarifying the role, and what I consider to be the seminal importance of the R&T Base. I will then discuss the seven key validation efforts, with emphasis on those for which congressional direction is especially important at this time.

THE RESEARCH AND TECHNOLOGY BASE

Technological advance is critical to all elements of our space program, scientific, exploration, and commercial. For example, although many valuable and exciting scientific investigations can be carried out in space with today's technology, major advances in optical resolution and telescope pointing accuracy are required to allow us to detect Earth-like planets circling nearby stars. Better propulsion, structural, guidance and control technologies are needed if our launch and orbital transfer systems are to be more reliable and economical. The technologies which are needed are many and varied. Some are rather specifically motivated by space needs, while many are of broad applicability. It is no exaggeration to say that applications in space are more technologically demanding than most terrestrial applications, in particular with respect to demands for reliability, low weight, and long life. Space needs force technology developments which can later provide large benefits in terrestrial applications, though the latter might not by themselves have provided sufficient motivation for the research and development.

These technological advances cannot be programmed. The character of research is such that, particularly in its early stages, its application cannot be reliably predicted. Research must therefore be pursued on a broad front, to identify and quantify technical possibilities, before their usefulness can be judged. Such research and technology program is therefore properly conceived as OPPORTUNITY GENERATING, rather than directed at known, specific applications. When the technological opportunities have been identified and the risks understood, it is then important to move aggressively to a level of thorough quantitative understanding to provide a basis for deciding whether and how to employ the new technology. It is this latter phase which will be addressed in the following discussion of technology validation.

How much support for the R&T Base is enough? This is a question on which recent administrations have had difficulty adopting a long-range view in the face of overall budget stringency and the lack of clearly definable products which may be expected of research in the near-term. Though few dispute the long-term benefits, the question often asked is: "why now, what's the hurry, can't we stretch it out?" There are at least two arguments which counter this view. One is that delay will cost us dearly in missed opportunities, in ideas and technologies which are evolved and pursued outside the U.S. But still, what level of support is required to ensure that we are not missing opportunities? I believe the answer is that we should provide sufficient support to make the best possible use of the precious resources of research talent presently in our universities and research laboratories, and to ensure that those bright young people who are interested in space will not be deterred from research careers by lack of financial support. In the end the answer still rests on informed judgment; it is the judgment of the National Commission on Space that

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the part of our Space Research and Technology Program supported by NASA should be increased by a FACTOR OF THREE.

TECHNOLOGY VALIDATION PROGRAMS OF HIGH PRIORITY

Technological research is essential and should have very high priority, but it is not sufficient to ensure the availability of the best possible technologies to our space programs. Before new concepts derived from research can be employed in expensive, tightly scheduled flight programs, they must be carried through the steps of engineering design, test and evaluation to the level of maturity at which reliable estimates of weight, manufacturability and cost can be made, before they can be incorporated in large, costly systems. It is essential that these steps be taken before systems commitments are made, because unexpected faults or difficulties which cause schedule slippage in large programs are extremely expensive, and to no good result.

The Commission recommends for special priority the following seven technology validation programs.

(1) Flight research on aerospace plane propulsion and aerodynamics;
(2) Advanced rocket vehicles;
(3) Aerobraking for orbital transfer;
(4) Long-duration closed-ecosystems;
(5) Electric launch and propulsion systems;
(6) Nuclear-electric space power; and
(7) Space tethers and artificial gravity.

I offer a few comments on each of these, but will dwell at somewhat greater length on the first two, which have gained a great sense of urgency since the loss of the space shuttle Challenger and the subsequent failures in other launch systems. It became very clear again to the public in the wake of these very visible incidents that Earth-to-orbit transportation, far from having become a routine endeavor, still presents technological and management challenges of the first order. While it is not a complete solution to the crisis we find ourselves in, better technology offers the possibility of design and development in the future of Earth-orbit transportation systems which can meet the difficult requirements with larger margins of safety, hence greater reliability, and eventually lower cost.

Future Earth-orbit transportation systems will consist of unpiloted cargo transport vehicles and passenger transport vehicles using improved and advanced technologies. Our review of the space transportation area led us to the conclusion that the technologies critical to achieving better unpiloted launchers center in the manufacturing of the principal components of the vehicle: materials, structures, engines, tanks, guidance, and control. A second critical need is to increase safety and reliability while reducing the size of the checkout and launch crews now needed to support launches. This can be done through modern, automated readiness tests combined with hardware and software which is more tolerant of minor faults.

For passenger transport to low-Earth orbit, we need reusable vehicles that are robust and reliable. Because of the large energy change required to achieve orbit, the propulsion system dominates the character of the vehicle. Amongst the options are one- and two-stage rockets with hydrogen/oxygen or hydrocarbon/oxygen engines, two-stage vehicles using airbreathing engines in the first stage and rockets in the second. The most challenging possibility under consideration is a single-stage combined cycle system using hydrogen for airbreathing propulsion to orbit, capable of horizontal launch and hypersonic suborbital flight in the atmosphere. This is the concept envisioned as an outcome of the National Aerospace Plane Program (NASP).

The propulsion technology base must be vigorously extended for both rocket and airbreathing engines. Advances in durability of the thermal protection system and in lightweight materials and structures will pay off handsomely in lower operational costs, as well as improvements in the information, guidance and control systems. These vehicles can benefit from the major advances in computer technology that have taken place since the shuttle was designed if programs are initiated now to develop space-rated, fault-tolerant computers. All of these areas will require early technology demonstrations if the improvements are to be validated in time for vehicles to be operational by the late 1990's.

For the airbreathing option, extensive research and technology development is needed, whether it is used in an airbreathing first-stage, or in a single-stage vehicle. Here the critical technologies are in the Supersonic Combustion Ramjet Engine (SCRAMJET), a propulsion device that has been well understood conceptually since the early 1960's but has been experimentally validated only in ground experiments, and only up to Mach numbers of about 8. If the SCRAMJET is to meet the expecta-

tions it has generated for orbital launch its Mach number range must extend to at least 12, and preferably to beyond 15.

The essential feature of the SCRAMJET is that the air is not slowed to low velocities before the fuel is added, as it is in all other airbreathing engines; rather the hydrogen fuel is injected into air flowing at Mach 3 to 8 through the combustion chamber and into the exhaust nozzle. This minimizes the problems of high temperatures and pressure in the combustor chamber which a conventional ramjet would encounter at very high flight Mach numbers. However, it leaves one very fundamental and difficult problem to be overcome. That is that the amount of energy added to the airflow by combustion of the hydrogen is small compared to the kinetic energy of the airflow into the engine, or by the same token small compared to the kinetic energy of the flow out of the nozzle. Thus the thrust, which results from the conversion of the fuel's combustion heat into kinetic energy of the nozzle flow, results from a small difference between the nozzle flow velocity and the flight velocity. This difference is only a few percent at Mach numbers above 15.

It follows that success for the SCRAMJET depends on extraordinary sophistication in fluid mechanical design, development and operational control. There is reason to believe that with modern supercomputer technology and experimental capabilities, a design can be achieved which will yield specific impulse values, averaged over the Mach number range from 0 to 23, as high as 1,000 to 1,500, which is two to three times that of a hydrogen/oxygen rocket. If these values can be achieved, the fraction of the vehicle mass which must be propellant may be small enough that single-stage operation to orbit becomes practical.

The critical issue here is the validation of the propulsion system at high Mach numbers. Since no ground test capability is available at such Mach numbers, and indeed none seems feasible, the propulsion system must be validated experimentally in flight. This is the principal purpose of the National Aerospace Plane Program, which the Commission strongly endorses.

Aerobraking is a critical technology for orbital transfer; by reducing the propellant consumption required to return a high orbit to a low-Earth orbit, it will reduce by as much as half the mass of the vehicle which is required to carry a given payload to a high orbit. Here the critical technologies are light-weight, heat resistant structures for the drag brake, and precise guidance and control for the trajectory, which must just "skim" the validation experiment.

Electric propulsion offers great benefits in reduced system mass for scientific missions requiring large velocity changes. Indeed, for some missions to the outer planets it is enabling. There are two elements to an elecric propulsion system: the propellant accelerator and the electric power source. One class of propellant accelerator, the "ion-engine," has been thoroughly ground tested and also operated successfully in orbit in small sizes. In these tests photovoltaic cells provided the power. While this is satisfactory for small thrust levels in the inner Solar System, the only practical power source for challenging missions to the outer planets is nuclear electric. We need a moderately sized solar-electric propulsion validation experiment to raise confidence in electric propulsion to the level that it can be considered for difficult missions, for which it is the only feasible alternative.

Nuclear-electric power offers much for space activities in combination with electric propulsion as just noted, as a compact, lower mass alternative to large solar arrays for space stations, and as sources of power for bases on the Moon or Mars. There is a program, cooperative between the DOD, DOE, and NASA, to build and ground test the components of a high performance nuclear-thermoelectric system capable of powers in the order of 100 kilowatts. This SP-100 program at present derives nearly all of its support from military sources. I urge you to be aware of its importance to our civilan space program as well.

The last technology for which a technology validation is especially recommended, the "tether" is a long tensile connection between two orbiting bodies. Because of the economies which it offers in transferring energy between the bodies and its potential for providing variable gravity, it is likely to play an important role in future space activities. It has been studied extensively, theoretically, but an in-space validation of these studies is needed soon so that the manifold advantages of tethers can be exploited.

In closing, let me note that the space research and technology development I have briefly discussed provides the seeds for our future in space. It provides both the knowledge and the people essential to our future. I hope you treat it favorably in allocating our national resources, for in this area I believe the return will be excellent.

Senator GORTON. Thank you.

Dr. Sullivan.

Dr. SULLIVAN. Mr. Chairman, Senator Hollings, it has been quite a pleasure and a privilege for me to take part in this exercise over the course of this past year. I certainly have learned a great deal from it, and I hope that in the end we have given you some appropriate information and a pertinent and perhaps useful roadmap upon which to draw as you form more specific proposals.

I would like to just highlight a few points very briefly. One is to say that it does seem in the current climate with all the very pressing and immediate problems that face the nation economically, and the space program technically and economically, this seems rather almost too glossy and too pretty and too fancy a book to have lying around on one's desk. It seems out of context. But I submit in concurrence with my colleagues today that it is not out of context at all. And I would offer two points on that subject.

One is that what we are talking about is providing starting steps along this path. This is a very broad, very general, very long term roadmap. It looks very large now, just as the prospect of getting your Ph.D. looks when you are four years old. And mercifully, nobody has to take all of those steps at one giant leap.

I think Dr. Kerrebrock has made some very pertinent points, and we have embodied a number of them in our technology development section to show that there are really quite doable, quite biteable chunks of effort in the scientific field and in the technology base areas that can be started upon today that one could regard as the seminal elements for any of these future scenarios.

And it may in fact be in the long run that we have missed the point entirely, and where the space program ultimately goes is very different than any of the artwork you see in this report now.

The key for the country, I believe, is that we as a nation and you as our leaders have well understood and well-worn tools in our tool kits at the appropriate times to make those decisions, to have the flexibility of response, to react to emerging conditions and new trends as they come along.

The aspect of having not adequately invested in our seed corn is one that we all felt very strongly. And I would just echo Dr. Kerrebrock's comments.

Manned activities and civilian activities were two subjects we discussed quite a bit in our deliberations. Civilian activities were, of course, the arena that we were mandated to address. I personally feel that a very healthy civilian space program is a very important aspect for this country to have in its overall policy. I think it is a very significant statement, if you will, of our national character and of our national heritage, that we have an open and public program that all citizens feel enfranchised in, that has the very deep and strong educational motivational drawing power that the program has had over its first quarter century, and that provides the somewhat more rapid diffusion of its experience and its technologies to the broadest range of sectors of public activity and private sector activities.

With respect to man in space, it is a complex issue. There has been, of course, quite a heated debate on what the appropriate balance, if any, should be between manned and unmanned activities for a number of years. Probably the most pointed debates come in the arenas of space physics and planetary exploration.

But let's please not forget that there still are several other disciplines of scientific activity, and I am thinking in particular of the life sciences and what might be termed in a very general sense chemistry, most currently today thought of in terms of microgravity research, in which man in the laboratory will probably have a very vital role to play for quite some time to come.

There has not yet been a Nobel prize awarded for research based on or in space. I for one certainly do not think that is because space is something we understand perfectly, or terribly simple, or there is no complexity out there at all, or there is nothing about the space environment or techniques that we can apply there and not on earth that might unlock some new secrets in prospects or products and processes that we thought we understood very well.

I think it is more a question of us not yet having properly equipped and really unchained the full range of creativity of our best minds in the space environment and about the space environment.

I think until we have provided that sort of activity with suitable opportunities for questioning in the space environment, that it will be premature to categorically state that we fully understand all of the relative balances that are appropriate for manned and unmanned systems.

I think there will always be a very healthy balance between them. We should look more at productive and positive interplay rather than an exclusive sort of role for them, and I think we will have a very bright and promising future if we can explore those balances.

Thank you.

Senator GORTON. Thank you, all of the members and panelists. This is the only time in all probability that we are going to have you here together. Therefore I cannot resist starting my questioning by pulling back from the long range to the short and middle ranges and asking you, Dr. Paine, and any of the other members who wish to comment on whether you think we ought to redefine the role of the shuttle, whether or not we should replace the *Challenger*, and what the relationship between the *Challenger*, or rather the shuttle and ELVs, should be in our civilian space programs over the course of the next decade.

Dr. PAINE. Well, Mr. Chairman, as you know, we were directed in our studies to accept the shuttle as a given, and not to study it any further, and the same with respect to the space station. We were to answer the question, what lies beyond these. So I cannot give you any Commission conclusion on this, although I could just give you a top of the head general statement that it seems very clear, and I think from our Commission studies, that indeed we need a mixed fleet. It is very difficult to design one vehicle that does everything. Usually that is a formula for an engineering disaster, and so in our studies for the post-shuttle fleet we recommended that one vehicle concentrate on passenger transport and a separate vehicle for bulk cargo.

The first could be, therefore, smaller than the shuttle, and the other vehicle could concentrate on low-cost delivery of cargo. This allows us then to do things that we would not do in a manned system, but both of these will have common characteristics.

One conclusion that has come out of the Air Force/NASA studies of next generation launch vehicles is that they will have a high degree of reusability to get the cost down, but equally important, they will also have a very high degree of automation, what we call artificial intelligence, to replace the large numbers of people down at Cape Canaveral looking at screens. This was very appropriate for the 1960s when I was at NASA, but today really represents a technology which can be replaced by much more automation.

The degree to which we are able to run the jet transport system of the world with a very high degree of reliability, with airplanes spending very little time on the ground, constantly being aloft, is the type of thing which we believe by the end of the century we can begin to approach with our space systems. That does not answer your question about the fourth orbiter. On that I would simply say that we need to take a very good look at the three different classes of launches that we need as a nation. We need the military launch capability. We need the commercial launch capability. And we need the scientific and development type of launch capability.

These work out to about a third, a third, and a third at the present time. We need to look at the future requirements for launch, and at the availability of the old military derived launch vehicles which have had a very long life but which suffer from the defects of high cost and a number of single point failure modes (when you design a military launch vehicle you do not design it with the same type of criteria as a low cost repetitive Boeing 747, for example).

So, I think my own feeling would be that we probably are going to have a very difficult time trying to get to the end of the century with three orbiters, but without having looked precisely at all of the payloads that need to be carried, and without looking precisely at the alternative expendable launch vehicles, I would not take a position. I think another indication is that the White House has been studying this now for a long period of time, and they still have not reached the judgment which would suggest to me that it must be a rather close call. There must be something to be said on each side.

Senator GORTON. Do any of the rest of you have a comment?

[No response.]

Senator GORTON. I see negative shakings of the head. All right, then, we will go ahead. Your recommendations are really quite clear in suggesting that human exploration and prospecting on Mars and its satellites wait until after lunar outposts and operations have been established. Other opinions and recommendations vary with that. What is the logic for delaying Mars initiatives until after lunar operations have been conducted?

Dr. WILKENING. We did not expect to delay all Mars activity until after we had established a lunar presence. There is still precursor type activity that we would expect to take place unmanned at Mars.

Senator GORTON. In what kind of time frame?

Dr. WILKENING. Well, as soon as possible, I guess. As you know, a Mars orbital mission has already been approved, which would fit well into that. We would expect that some time in the 1990's there would be a sample return mission with further exploration of Mars. I think these are necessary to establish the base of knowledge that we would need to plan any human activity at Mars.

I guess I would go back to my statement as for the logic surrounding our expansion. In my statement, I said that we did not wish to pin our recommendations on a single space spectacular, that we feel that space offers such a diversity of opportunities that it is not something that we want to just do once and say, well, that is it. We really saw a logical expansion of activity moving out from earth orbit, out possibly to the libration points and on to the moon and then to Mars. We would see the reusability of the same types of vehicles and systems that are established in earth orbit, using those same systems at the moon and then Mars. In that way we would hope reduce the cost so that you do not have to invent something every time you wish to establish a new space craft or transfer vehicle.

Dr. SULLIVAN. Mr. Chairman, another aspect of that logic had to do with what is coming to be known as tele-presence. It is another term, for the application of automation in robotics technologies to varying degrees guided directly or by remote control by human intelligence, transporting human capabilities by machine presences to remote areas. The success with which you can accomplish such things by true interactive human guidance does, of course, vary with the distance. It falls off with the distance away from your control site. The sorts of signal delay times that one would encounter in attempting to direct, for example, a semi-autonomous prospector on the moon from a station on the ground are on the order of a very few seconds. It might be feasible to operate that way with a minimum human presence or a periodic human presence on the moon, at least in some early phases, and the remaining bulk of the activity would be conducted over a longer time frame from stations here on the earth.

When one considers going on to Mars, of course, the distances, and therefore the signal delay times, are much greater, and they probably exceed the realm of possibility for tele-presence. The alternatives, then, are to be so smart about what you want to do before you go there that you can pre-program a sequence in hardware or software memory and just initiate a start command and let it go, which is effectively what we do with Viking and Voyager types of spacecraft. Or you send human beings there to take charge in real time of the unexpected and unanticipated events as they unfold, and respond to them and learn from them.

So, there was a learning aspect, an evolution of technologies, and an evolution of the experience base implicit in our scenario that showed some return to the moon before a return to Mars. I am sure you can appreciate, though, that in attempting to describe in one single book a set of activities that we hope will occur as much as possible in parallel, it becomes impossible to trace all of the convoluted interactions and the sequential dependencies.

So, we did tend to present the final step of evolution of a full lunar base and only give some sense of the precursor stages it would have passed through before it becomes a full-fledged mining activity, for example.

Senator GORTON. What is the time delay of the speed of light going to Mars?

Dr. SULLIVAN. I knew you would ask me that number! I do not have it.

Dr. FIELD. A few minutes. Five minutes. Depending on where we are in the orbit, it is about on the order of 5 minutes or so.

Senator GORTON. Your last answer, Dr. Sullivan, raises additional questions, or at least has some implications to one of the most fundamental questions that we are faced with, and that is the the extent to which we should be involved in manned exploration of space. That is highlighted, of course, by the *Challenger* disaster and by the fact that we went some 6 years or so with some considerable space successes without manned missions at all. Under those circumstances, and with the obviously much greater costs and greater time constraints, what is the justification for pursuing so aggressively a program of manned missions as the Commission outlined?

Dr. FIELD. Maybe I should take that one.

Senator GORTON. I would be happy to have any of you answer.

Dr. FIELD. Mr. Chairman, I am probably not usually in the center of this kind of debate, because as an astronomer, I have been most involved in the results that come from the unmanned program, the telescopes which have been put above the earth's surface, some of which, by the way, in my opinion, are of Nobel prize quality. It remains to be seen whether the discovery of black holes is fundamental in that sense.

But my personal feeling is that the space program represents the property of the American people, and it is not for the scientists. It is not for the technologists. It is for the people as a whole. There is a tremendous pride in the space program that we found when we traveled around the country and talked to people. Part of their pride is that we have had the daring to mount a manned program and to do it successfully, and in a very fine fashion.

I think that the sentiment in the country is that we should go on with this activity. We should perhaps restructure it, think through carefully how we do it, and the purposes for which we are doing it. I support that point of view, even though I, as I say, am not personally involved in the results at this time from a manned program. There are specific issues that involve astronomy in the future. There are tremendous possibilities in doing astronomy from earth orbit and from the surface of

the moon, and they would involve men, simply because the facilities that we would like to put there are so large that they cannot, as far as we can understand now, they are so complicated that they could not be built and maintained without the intervention of man.

But that is not the issue, I think. The issue is one of the spirit of the American people in moving out into space, not only technologically, not only scientifically, but in a way that the man in the street can identify with—namely individuals going there. We found that spirit far and wide across the country, expressed very positively. I took a little telephone poll of my own, just going through the telephone book in my home town. I got a very positive response on that, obviously not scientific, though.

But I do think that where we may have gone awry a little in the past is that we did not have a well structured set of plans after Apollo which would dictate when to use man and when not to use man. We were trying to do everything in the manned mode because of the constraints of the shuttle program, and we were not arguing from the goal back to what we should be doing, but rather, we were doing things simply because the technology had been specified to be that way.

I think that the crucial point that the Congress should consider is to establish a goal which can be accepted by the United States as reasonable and effective and challenging and interesting to the man in the street from which we can then derive whether a mission should be manned or unmanned, and it is perfectly clear to me that many of them will be unmanned and others will have to be manned, and of course those criteria will change as we go along.

I would like to see the Space Act of 1958 reconsidered, perhaps rewritten to reflect this kind of thinking so that we can respond, as the other speakers have said, to the conditions as they come along year by year in a flexible fashion, but always referring back to the philosophical base that we have built for ourselves. If we can do that in a proper fashion, I think the question of manned versus unmanned can be solved as we go along.

Senator GORTON. Dr. Paine.

Dr. PAINE. I might just offer a comment on the question of manned versus unmanned, which I think in many ways is not the most solicitous formation of the question. I think really the question is what is the best mix and interface between men and machines to get the job accomplished. When you look at it this way, there will certainly be people who will opt for doing everything with men at one extreme and at the other extreme doing nothing with man, but it really is much more a question of what is the best balance.

I think that throughout our report, Mr. Chairman, we were faced with similar mixed questions, what is the best mix of science and commercial activities, what is the best mix of government launch versus privatization of launches? What do we want to do to get early returns of economic value to justify the space program versus the longer range opening of whole new worlds?

We talked to people who would take a position that the real emphasis in the space program should be military, that it is really national defense, and everything should be done militarily. We talked with others, who would argue that everything should be done for science, with others, that everything should be just exploration or applied. What we have tried to come up with in our report to you is what we regard as a balanced program that has the mix of these different things that we think can be sustainable for the next several decades.

Senator GORTON. I have one other question. You spoke of intermediate missions to Mars, and that was also the subject of your Commission's report on possible cooperation with the Soviet Union and cooperation beyond that. Is at least the prospect of intermediate and unmanned missions to Mars or cooperative endeavors with respect to Mars something which you think is achievable? Do we have difficulties that are relatively easily overcome, or extreme problems that may not be so easily overcome?

Dr. PAINE. Well, I think it is something perhaps in between. In the course of our studies I was invited by a House committee to travel to Moscow, and it was a very interesting experience that enabled us to talk to scientists on the bench and engineers that were studying their long-range habitats that will make it possible to have closed ecology systems outside of the earth's atmosphere. We talked all the way at the top to Andre Gromyko, the president of the Soviet Presidium. The range of viewpoints that we got was quite interesting.

In general, the scientists at the bench were extremely anxious for an opportunity to go work at JPL or Ames for a year. That would be just the most magnificent thing that he could see in his career. As you went up the ladder, you got the same desirability to cooperate with the Americans from section chiefs or laboratory heads, but with the caveat at the beginning that it must be understood that there are political differences between our countries which must be taken into account.

At the level of the Soviet Academy of Sciences, we encountered rather vigorous camplaints that the Americans really want to militarize space, and how can we cooperate with our fellow scientists if they are militarizing space. Of course our answer to that is, well, how can we cooperate with our fellow scientists if you are throwing them in jail and exiling them and muzzling them?

The discourse began to get a little sticky, and then when you got up to the level of professional diplomats like Andre Gromyko, it was pretty much a shouting match. You may recall that it fell to meafter the end of the Apollo missions to initiate the discussions with the Soviets that led to the Apollo-Soyuz mission, and as you very well characterized, such negotiations are very difficult. One needs to be very patient. There is a good deal of suspicion on both sides. Clearly, we are not at all anxious to have technology transferred to them. The way they put it is, they do not want a bunch of American spies getting to their laboratories. There are all the difficulties involved of the relative credits. Are we going to be characterized by wanting to cooperate with the Soviets because we are behind now, or are they going to be so characterized because they are behind? So there are many sensitivities.

But I think the overwhelming benefits to both nations of moving toward greater cooperation in space are so great and so obvious that I would be quite optimistic that a patient, prolonged movement in this direction would probably be crowned with some success, and in our report you may notice that one of the pictures that we had the artist depict is a rendezvous on the surface of Mars between an American artificial intelligence Rover that has been wandering around for about a month collecting highly characterized geological specimens, approaching the Soviet vehicle, which has the capability for sample preservation and sample return to earth.

There have been discussions back and forth between our scientists of such a mission, including the question of, if we did such a mission, to where would you bring the samples back? If you brought them into Siberia, how do we know we would ever see them? One of the Soviet scientists actually suggested that if the United States really thought it would be a problem, he would be quite prepared to have it return into the United States. He did not think that was a difficult problem.

So, this has gotten a fair amount of discussion. The initial suggestion pretty much came from a Soviet scientist. I think the place to start is probably at the robotic level with a precursor mission of that type. Then there would be no problem of technology exchange. There would be no problem of, if one nation failed would the whole mission get scrubbed, because there would be a perfectly good Rover mission for us even if the Soviets were not successful, and for them it would be a perfectly good sample return. They could grab samples from near the landing site that would justify their mission. But if both of our missions were successful, we would multiply 100 times the scientific return.

I believe that if such a precursor mission were carried out, that indeed, as we moved toward the era of manned missions, that there very likely would be a way of looking at it.

Senator GORTON. Thank you.

Senator Hollings, do you have any questions that you would like to ask.

Senator HOLLINGS. I am fascinated and obviously thrilled at this report. Three years ago when I introduced legislation to create the National Commission on Space I did not have in mind that we were going to be at this particular critical stage. I was looking for myself to Congress and trying to get a charter. Now more than ever we need a charter. And I learned to try to focus the mind as a candidate at one time, what would you do as President, and every problem that we confronted in all the debates and all the travels, you more or less had to ask yourself. I mean, you are doing all this complaining about the economy and about this, that, and the next thing, and what would you do with the military, what would you do with the Soviets, what would you find? At this critical juncture, what would you have the Congress do, or what should the President do or recommend? Because momentarily we are stalled. I do not know how to get better talent than the group assembled in this room.

I apologize, by the way. We could get a way better hearing, and could get more publicity somehow if somebody here said one of the persons over at NASA had fudged a little on safety procedures or whatever. Then we would have the *New York Times* and 12 newspapers and all of the TV people here and everything else.

Now, the best thing that has happened to the civilian space program is namely you and your Commission and your report, and we have nothing. Nobody is here but us chickens. Tell us, what would you do now that we are presently stalled? Give us a one, two, three, four. We have to get some direction. I mean, we have so many questions to answer. To our colleagues, we recommend $100 million or $2 billion or no money whatever. They want to know why, and I could get a better idea from you than anyone else.

Dr. PAINE. Let me address that question, but if I may, Mr. Chairman, before I do, I would like to give my heartfelt thanks to Senator Hollings. The first letter that we received in the National Commission on Space after we sent out our report was from Senator Hollings, and it was a most gracious and warm letter. You know, when you shoot that arrow into the air, and then you sit there wondering what the reaction is, to get that letter from you, Senator Hollings, was a wonderful experience, and gave us a lot of encouragement.

Senator HOLLINGS. Well, you are more than welcome. That was the intent. I know you folks have been working a year. It has all been missed. Frankly, there are colleagues on this Committee who did not realize all of the endeavor and study and dedication that went on by all of you on the Commission. Generally all of us are very grateful to you.

Dr. PAINE. We are very grateful to you for that early comment. Let me just say that there are several things that we emphasize as far as immediate actions. The thing that we wanted as a specific action now would be to have this Committee direct the administrator of NASA to study our report and to come back and report to you and report to the President by the end of the year on the implications for any future direction and pace of the American space program, and what specifically NASA would undertake in order to implement this long-range set of goals, the space agenda that we have proposed.

Now, you could raise the question, with all the difficulties that Jim Fletcher has, would this be an imposition on him to add this to his load? He was good enough to come and address our Commission's last meeting yesterday, and it certainly is my impression that he would be delighted to be asked such a question, and that the people within NASA's organization who would be required to prepare such a response are not the people who are addressing fixing the shuttle, people that are really now looking at the long range future, and this would give them a focus and a direction.

So we would hope very much that you would make such a direction to the head of NASA. There are three things. That is the first. Secondly, I think we have shared with you on this Committee a feeling that the response at the national policy level to the *Challenger* disaster has been rather slow, and that as a result, a certain amount of shall we

say in-fighting between NASA, the Air Force, and budgets and so forth has been carried on that crisp decisions might have prevented.

We have proposed in our study that the old National Aeronautics and Space Council be reactivated. When I was the administrator, it existed. It is uniquely capable, I think, of addressing space policy questions, not short range operational but long range where we are going questions. It is authorized in the original NASA authorization, so there is lots of legislative history, but during President Nixon's administration he discontinued the science advisor and the National Council.

Since that time, the science advisor has been reinstituted by action from Congress, and we would suggest that you look at the question of reinstituting the National Aeronautics and Space Council.

Now I do recognize that telling somebody how to organize his staff is perhaps a little bit officious. But, nevertheless, I think that looking at the requirements for developing space policy on a sound basis and the need for doing this perhaps in a crisper way than we are doing it now gives us the courage to make such a suggestion.

Thirdly, I would just emphasize what Dr. Kerrebrock has said.

While NASA is preparing a longer range plan at your direction, and, we would hope, along the directions that we have proposed, or, in any event stimulated by our proposals, I think it is very important that we move rather quickly toward restoring the technology base that NASA has been neglecting for some years.

It now represents 2 percent of the NASA budget, and I do not think there is an industry in this country that would try to get by on a 2 percent R&D budget. If there is here, there certainly isn't one in Japan. We would like to see that back up to around 6 percent of the NASA budget relatively quickly.

I think you can justify this on the basis that it will allow us in the early 1990s to make the right decision with respect to the post-shuttle launch vehicle mix because we have developed a technology that will allow us to design more reliable, lower cost systems. Then we can decide whether it is going to be an aerospace plane that uses air-breathing engines or whether it is going to be a new generation of rocket plane. We should make that decision in a crisp way, based on the technological results from the laboratory that give us confidence, including actual flight tests of an aerospace plane. Then I think that this technology base will pay for itself many times over.

In addition, one of the reasons we found as we talked around the country that NASA is supported, and I am sure one of the reasons why this committee has been so steadfast in its support of NASA, is because we expect to come from it a series of technological advances that will help broadly both the American economy and the American security in the long run.

Again, moving NASA out to the forefront of the technologies that we are recommending will have a major impact on the competitive strength and the national security of this nation in the 1990s and indeed in the next century.

I might just conclude by saying, on that point, that you gave us the charge that not only should we propose a space program that would still be valid into the next century, but also that we try to consider the broader values of American society that are likely to exist at that time and to propose a space program that will support them. That was a very difficult assignment, indeed, but led in many ways to some of the most interesting parts of our study.

As we looked at the nation in 1935 and tried to foresee what we would have had to have done to predict the 1985 America, it was very clear that we should have gone to the laboratories and talked to the people working there. We should have talked to Frank Whittle and von Olhehn in Germany about this new idea they had called a jet engine. If we had, we might have been able to predict that the economy of your home State would be heavily involved in meeting the needs of the jet global transportation system of 50 years later.

We could have talked to Robert Goddard and Wernher von Braun in two different nations about the importance of a liquid fuel rocket for the future. We could have learned many of the things which have become growth industries in our time but for which the seed was planted then.

We would like to believe that the kind of technology support program that we are proposing here has similar implications for our country in the next century, particularly robotics, artificial intelligence and automation, which we think will be used throughout our manufacturing industry, keeping it competitive in the coming decades. Also the whole new area of the life sciences and biological engineering techniques that are moving forward so rapidly now, which will be absolutely essential to the closed ecology life support systems that we envision and that we propose get support now.

So it is really three specific short-range actions.

We think it is terribly important that we take a look at the technology base underlying the space program to make sure that it is getting adequate support in the very near term.

We think it is very important that we take a look at the question of national space policy development and whether or not the Space Council might be a way of improving that capability.

Thirdly, we think you should direct the Administrator of NASA to examine the proposals that we have made and to come up with a plan implementing them along the future direction.

Senator HOLLINGS. The Chairman has just commented that we will have the head of NASA look over and make comment on this report and we will have a hearing about it. Senator Riegle and I have already introduced the Council measure, and we will look at the various technological advances and try to prioritize those.

But let me ask this distinguished panel if there are any comments from any of the other panelists or any emphasis that any would wish to give?

[No response]

Senator HOLLINGS. I see that you have overwhelmed them. You are a pretty good chairman if you can keep the panel quiet.

Dr. PAINE. The most interesting page of our report so far as I am concerned is the page that has all 15 signatures on it.

I think we did reach quite a consensus, even though we came from many walks of life—test pilots, representatives to the United Nations, distinguished scientists, and people from industry.

To me, it was rather remarkable that we were able indeed to come out with a report that had the suport of all 15 of the Commission members.

Senator HOLLINGS. I would not want to bog down this scientific panel with the political problems, but we do have the immediate problem of replacing the shuttle, and whether we have a fourth orbiter.

Would you have a comment on it? Would you care to comment on what we should do right now?

This is pressing upon us. Senator Gorton, Senator Rockefeller and I are providing some money in the fiscal year 1987 NASA authorization, but we are just shooting in the dark. We don't know. We understand that there is a difficulty in getting a fourth orbiter, that we might be wasting money, according to some, and not advancing with the technology.

Can you comment on that?

What would you do right now? We can get the report from Dr. Fletcher, but we only have about 20 days between now and recess in August, and another 20 or 30 days when we come back after Labor Day. So time is of the essence.

In those two 20 day bites, something is going to have to be done. We hope to act as intelligently as we possibly can, and you are the only folks who I would say everyone has confidence in.

Tell us what to do.

Dr. PAINE. Senator Gorton has put this question to us, and we have taken refuge in the fact that we were specifically told to take the shuttle program as a given and not to investigate it. So, in a sense, we are laymen when it comes to that question.

But I think we could certainly say that the fact is that when we were looking at the technology development program for an aerospace plane, we were actually shown viewgraphs, which I saw as Administrator of NASA—the identical viewgraph which I saw as Administrator of NASA 16 years ago.

So we have really had a very starved advanced vehicle development program. I think the answer to the question of whether we should go to a post-shuttle vehicle now instead of a fourth orbiter is that it is simply not possible because we have not done our technological homework and are not ready to design a vehicle that is more advanced.

Now, you can get an idea from the study that the President requested the Air Force and NASA to make a little over a year ago. They are just about to their final conclusions now on the unmanned cargo vehicle.

I think their conclusions basically are that it will be some kind of reusable vehicle with a high degree of automation in launch operations to reduce the costs out of all the people that now have to be involved. And it is very likely going to be a pretty heavy launch type of capability. If you then have a very heavy cargo capability, certainly can develop a specialized passenger vehicle that does not need to have anywhere near the cargo capacity of the shuttle. By designing a specific vehicle for that, you probably can come up with a very good vehicle.

But, in our view, this vehicle would not come on line usefully until the late 1990s. We believe there is about a 6 year technology development program between now and 1992 or so which would include a flight demonstration of an aerospace plane, followed by your decision to go ahead with these two launch vehicles, the automated cargo and passenger vehicles, and then there would be another 5 or 6 years to put them into place. So, by the end of this century, you would have this new system.

At the present time, we are pretty well stuck with the vehicles that we have, and particularly with their capacity.

Senator HOLLINGS. Could we get a manned space station with the vehicles that we have?

Dr. PAINE. I think that is one of the questions you are going to have to resolve.

Senator HOLLINGS. I would never know the answer. I am going to have to find out from you.

Dr. PAINE. Well, there are two ways to go here.

One way is to continue the basic supposition on which the present space station program is built, that everything will be a cargo fitted within the shuttle bay, taken up and assembled in orbit. The other is the way of bringing on the heavy lift cargo vehicle early enough so that when you are ready to begin putting the space station elements into place, you will be able to take up much larger pieces at a time and then link them up in orbit.

My own personal view is that probably this is a question that is going to have to be addressed in the next few years. It will be reopened, because right now, our policy is to do it purely with the shuttle. My guess is with the shuttle delays, you are probably going to want to relook at that question.

Perhaps Dr. Sullivan and Dr. Kerrobrock would be very well placed to give you comments. As I say again, not only were we told not to look at the shuttle program, but we were also told not to look at the space station program.

Senator HOLLINGS. I know. But this is a good advantage—and I will then yield to you, Jay. I did not mean to take up so much time.

Dr. Sullivan, would you have a comment?

Dr. SULLIVAN. Yes, Senator Hollings.

I would say that it is, in my opinion, certainly possible to have a manned space station with shuttle or with a mix of shuttle and expendable launch vehicles. The key question is what should that station look like.

That, I think, is something that needs to be judged very critically. Of course, is a critical review going on within NASA at the present time.

It is not clear to me that the latest drawings of the proposed NASA baseline are, well, I won't say infeasible, but they provide a margin for accomplishment within the capabilities of the shuttle program. I am a systems operator. I do not believe in operating on the very ragged edge of your capabilities, at any rate not for very long.

Again, we are getting back to the same fundamental point that I think has been underlying all of what we have been saying this morning. A key element in all of our deliberations is the presumption that with the adoption of a roadmap of broader scope, broader term goals, one then has the basis for judging such questions on their merits. One can ask, here is this national science agenda, and how well does that space station serve this national science agenda, and maybe a national science agenda and an international relations agenda, so that we want cooperation from other nations in the Western World.

Similarly, when one looks at a proposal for a next generation vehicle to fill out the shuttle fleet and provide continuity of access to space through the end of the century, one can ask: Here is my agenda. It is both to get scientists and engineers to low earth orbit and to get astronomers to the far side of the moon for the radio telescope phase, and to begin construction of a spaceship. Does that new vehicle design serve all of those functions or have I purposely tailored it to fit one of those functions.

You have a basis, a set of criteria on which to judge each design by some objective set of merits. It is no longer an issue for any given agency or part of the government of pure survival to have a program continue for the sake of keeping an agency or a set of jobs in place. It becomes truly a national agenda. It has some national purpose and it has some clear criteria for judgment.

In this vein, I would urge that the committee pay some particular attention to a statement which is very brief, but I think very crucial in our report, which appears on page 109. It has to do with continuity of access for civilian purposes to space, initially to low earth orbit, but to space in general in a broader scope.

I think we are unfortunately, quite tragically, and painfully learning the lessons of not having that access in today's environment, as a function of both the *Challenger*, Delta, and Titan failures. It has become very rapidly and very deeply apparent, I think to all of us, just how severe a situation it is.

So, as the committee deliberates as to whether it can adopt certain goals and objectives and how it can determine what the proper succession of vehicles or cargo elements should be for the nation, I would urge that you give careful thought to that objective; that it is imperative, I believe, for the scientific, technological and economic health of this country through the end of this century and on into the Twenty-first Century that we no longer, and never again, have a hiatus of this sort.

To me, this says that we need to have a fairly flexible tool kit with some depth to it, so that when we have a problem in one area, we have other options, that we have other capabilities.

Senator HOLLINGS. Dr. Kerrebrock.

Dr. KERREBROCK. Let me second what Dr. Paine and Dr. Sullivan have said and attempt to answer your questions very directly.

I think we should buy a fourth orbiter.

Let me tell you why.

It is a fundamental mistake to try to operate any program, and certainly a high technology risk critical program, like our space program, hardware poor or resource poor.

Now, at the present time, every launch capability that this nation has and is projected to have for the next 7 years at least, maybe longer, is scheduled for some kind of payload. If you look at the manifest that DOD has constructed for the CELV and not just the 10 that they have funded, but the 13 more that they hope to buy—if you folks authorize it—those things are all scheduled for payloads.

A very large fraction of the launch capability of the three remaining shuttles for the next several years, after they go back into operations, are tightly manifested.

Now, it seems to me that such a system should have some excess capacity, and, furthermore, that the price of the new shuttle at this time may turn out in latter years to seem rather small compared to the cost of another shut-down of the nation's space program which, make no mistake, we run the risk of if we do not replace it and make sure that we have enough hardware assets to operate the program in a sensible, relatively low risk way.

Now, I think that that choice should be separated from the questions of investment in the next generation of a space transportation system, which we have mainly discussed in our report and which we were charged to discuss quite properly.

Those investments must be made also, so that when the time comes to invest in the next generation of transportation systems, which do have the potential for being more reliable and in some sense more cost effective—I am not going to say "cheaper," but more cost effective—we will have the best technology possible to go ahead with those projects.

But I think that is a different question than the rehabilitation of the present system.

Dr. PAINE. I think Dr. Sullivan wanted to add something to her comment.

Senator HOLLINGS. Surely.

Dr. SULLIVAN. I would make just one other point about replacement of a fourth orbiter in the sense of a vehicle that is very much a clone of the three we have now, within the limits of what we can currently purchase in terms of duplicate components.

The national space transportation system, the shuttle, is, of course, a manned system, and it is operated by a cadre, a large cadre, of people. It is very difficult for me to conceive that either the hardware support facilities, in the form of simulators and software development facilities

and engineering test laboratories, or the people themselves could effectively handle operating a four vehicle fleet of any sort in which the fourth vehicle was dramatically different than the other three but was being operated in sequence with them.

So I would caution against falling into the tendency of wanting to be at the state of the art and buy the newest thing off the shelf, and wondering why can't we have those computer screens that look so neat on my MacIntosh at home and how come I have this one in the orbiter. Frustrating though that may be at times, and as restrictive as it may be at times, from an operability point of view, I think there is some great wisdom in looking at the fleet size in terms of common vehicles.

I think four provides a little bit of excess capacity, but barely any for the near-term, and three certainly does not. I would be very cautious about proposing an orbiter Mark II and presuming that it could be operated without extremely higher costs and greater effort and greater risks in concert with the other three.

Senator HOLLINGS. I thank you.

And I thank you very much, Mr. Chairman.

Senator GORTON. Thank you.

Senator Rockefeller, do you have an opening statement?

Senator ROCKEFELLER. No, I don't.

Senator GORTON. Then go ahead with your questions.

Senator ROCKEFELLER. We are operating at several levels here, and I want to say that I share Senator Hollings' feelings.

I did not hear what Senator Gorton opened with about you, but I am sure it was in the same vein. So the tragedy of this hearing room today is that we are not loaded down with people eager to hear you.

I have not read your volume, though I have read parts of it. But it is really what we should, in the Congress be doing—you are doing what we should be doing. This is to be expected. You are experts and professionals and we are generalists.

But there are some things that sort of gnaw. One of them in the mundane matter of money on the one hand and where it is that you want to see us going on the other.

We are fooling around here with a $7-plus billion NASA budget, which includes no reimbursements for lost shuttle flights that we have missed, customers who have to be directedly compensated for not having gone on up, down time, the Rogers' Commission and $300 million to implement that, the need to procure more ELVs to handle certain kinds of very time-sensitive things that we simply have to do, that we just must do. There is even the question of the fourth orbiter. Now the delay has taken that from maybe $2.3 billion to $3 billion.

So we are talking about several billion dollars. Also a number of contractors have closed down their production lines on all of this in the meantime. We are talking about if we were to get a new orbiter, if we were to have one delivered by the 1990s, NASA would probably have to pay $150 million this year, and $500 to $600 million every year until then.

So here is our budget, which you may or may not reach, plus all of these things which we have included, which are mammoth, billions, in their add-on costs. This is one side of it.

Then I listen to Dr. Field talking about the spirit of the matter and how this is for the people—for the people, and that there has to be a philosophical base for this.

Dr. Paine, you are very, very strong, and I thoroughly agree with emphasis on the technology base and your use of the jet as an example. Who would have known that 35 years ago?

There is a link between technology which we have to do now for payoffs for people, ordinary people, 20 or 50 years from now. And you ask can't we get it from 2 percent to 6 percent for the technological research part of the budget.

And yet, we are probably in the hole billions as we sit here.

This is the weird part of this whole space program business. We are talking and dreaming on one level, and we are funding down here, and we refuse to discipline ourselves to talk at two different levels. We prefer to talk at the higher level, and we do talk at the higher level as we budget at the lower level and hope nobody notices.

But, eventually people add up the difference and they notice the difference, and the science stops, and the construction stops, and people go into other fields, and then people begin to write about it, and the public sense is to do something different.

The shuttle was a tremendous, a terrible disaster. But maybe the 2 percent is a great disaster, too.

Now, just to help me understand more properly this subject in terms of space for the people, as Dr. Field said, you said that you want this to affect people on earth in good ways. You mentioned artificial intelligence, robotics, life sciences, biological engineering.

If I am somebody in Cincinnati, OH, trying to understand the space program and why it is that all of this money goes into it, and now I don't see those things going up on television anymore, so my "pride," which is quantifiable only of the moment and of benefit in ways which do not directly help citizens and their lives—help me understand how the space program, if we do technology properly, if we fund the 3 percent or the 5 percent, much less the 6 percent or the 15 percent that one of your critics feels we ought to be increasing the budget by each year for NASA—tell me more what exploration in space could mean for people in their daily lives? What could it mean, for example, for cancer, for anemia, for cures for those? What kinds of things can people relate to—for the people—out there in the future?

Dr. PAINE. I think that that is a very eloquently phrased but extremely difficult question. It is one that we gave a great deal of thought to.

Our view was that the most important return that we get from the space program that is directly applicable to people here on Earth is the expansion of science return, which is perhaps the most difficult to quantify.

We know that past scientific advances have given us the ability to sit here, in an air conditioned room, with electric lights and all of the other benefits of modern civilization. Cures for polio and all of the things that have come from our increased scientific understanding have developed as we pushed out that frontier of human knowledge.

Indeed, I think we can characterize ourselves as living in an era known as the Industrial Revolution, which has only partly taken place. We are probably about a third of the way into the Industrial Revolution, which really constitutes the organized gathering of scientific, technological, and economic information, making rational decisions and making long-term investments in new techniques and capabilities that will allow us then to greately increase the productivity of our people.

We have increased the productivity of our farming to the point where 10 percent of our population can feed not only everyone in America, but they just wish there were more hungry people overseas on what we could unload some of our surplus.

We have reached the same stage in our industrial productivity, where an average worker today can turn out enough so that the total product which every person on average in the United States gets per year is now $14,000 worth of Gross National Product.

This is all because of productivity increases, by moving science and technology forward.

We are not sure what the discoveries are out on the space frontier that are going to be the most critical ones.

I recall a rather trite statement that was made at the time nuclear fission was discovered, about what a silly thing it was to hand out Nobel prizes for people who were splitting atoms—something which in World War II suddenly became of the highest national priority so that we would be able to take advantage of this whole technological revolution that was coming from this piece of science.

We do know that out in the universe, in the area where my distinguished astrophysical colleague works, that there are energetic processes taking place in the vicinity of black holes and other things which completely dwarf fission energy and fusion energy. There are processes in the universe that have enormous outputs of energy. If we could ever learn what they were and understand how they might be tapped, there is no question that we would transform our life here on Earth.

The ability to use space for such things as communications has had a major impact on us. The fact that an entrepreneur from Atlanta, Georgia, can go to Moscow and invent a new kind of game and then do it on the basis that he is going to sell advertising back in the United States is all based on the ability to put color television signals back and forth at very low cost through space systems.

At the time that we were first experimenting with going into orbit, nobody would have foreseen such a business development.

Similarly, in the field of medicine, Dr. Sullivan, distinguished, of course, as the first American woman to have walked in space, emphasized the fact that the physiological effects in orbit, of microgravity on the human physique, is teaching us a number of things.

We do not really know what the relationship is between the very dramatic difficulty called osteoporosis, which many older women get due to calcium loss, and calcium loss in orbit except that some of the things we are learning from the one will probably spill over into the other.

But I would emphasize that we will get practical sytems, like weather satellites and communications satellites. We will get systems such as the navigation satellites that are now in the military, which will then move over into the commercial sector.

We will get systems which will allow us to look down at the Earth from orbit and greatly increase the effectiveness of our prospecting for minerals, to help monitor our agriculture and indeed the whole state of the planet.

We will very likely, from our scientific understanding, begin to see how the increase in the carbon dioxide in the Earth's atmosphere is going to affect future climate in the next century. Are we going to go through a great period of heating? Are the glaciers going to melt, and the icecaps, and the water levels to rise? Or is this a boon, on the other hand, that will probably make agriculture flourish? Or perhaps we are going into a period of global cooling, and this will very nicely compensate.

We don't know these things.

But we do know that space research is giving us a much better handle opn the questions.

If we set ourselves tough goals, like, for example, closed ecology biospheres that will allow us to live off the land in other worlds, we are quite confident that we will learn whole new approaches to agricultural productivity here on earth.

We do not really understand all of the parts of the food chain, all of the little micro-flora, the things in the soil that are so essential to agricultural production in ways that are too complex to understand. But, when we begin to try to operate these things on the Moon and on Mars, we are going to have to understand all of the parts of the process. We will learn an awful lot from our failures. And it may well be that out of developments like this will come whole new approaches to agriculture, so that if you want to make the American Southwest or the Sahara Desert blue, instead of doing it the way the Pharoahs invented—which is to get a bunch of people to dig a ditch from the river over and to put up an irrigation system—perhaps you will just truck in a new supply of water, put it in a closed container, and with modern science and technology have a tremendous output of agricultural food and fiber without the necessity for large usages of water.

We don't know whether that will come out or something else. But we are very confident that the kind of broadly based technological program that we are proposing here, based on everything that history has taught us, from the technology advances of World War II, put out into a vigorous space program in the future, will undoubtedly bring large amounts of benefits to people, but in ways that are very difficult for us to understand.

Senator ROCKEFELLER. Let me just press one point, Mr. Chairman.

On the medical side—and perhaps Dr. Sullivan can be of help on this—you mentioned some of the problems associated with aging and certain solutions from zero based gravity, et cetera, that might be discovered. I have heard of a process called electrophoresis, in terms of work with cancer and anemia and other things, I have heard of things that relate directly to lives of individuals, and not just the cooling or warming of the Earth, which is cosmic and global, but things with individuals, where people can see changes. I am told that absolutely perfect spheres, totally perfect spheres, can be made in no places as perfectly as they can be made up there in space.

Well, that might not be medical so much an industrial. But the medical part interests me, and it is never discussed.

When I see the techological base part of it, and when I look at our horrible financial situation, I worry. We are always talking about the fourth orbiter, and this or that. But the anemia part, the cancer part, the potential for aging, do not get discussed enough.

I want a little bit more of that, and then I will defer back to the Chairmian.

Dr. PAINE. I would merely comment, Senator Rockefeller, that if we can indeed begin to sustain human colonies with completely detached biospheres, we will have the most magnificent laboratory that ever existed for actually understanding all of the ways in which humans interact with their environment to attain health, longevity, and all of the other things, and, conversely, we will undoubtedly learn some things, that go through the population. But we will have the ability to carry out biological experiments that very likely would be too dangerous to carry out otherwise.

We will have the perfect isolation laboratories that will allow us to learn much more.

There is no question that we are in a micro and macro molecular revolution now and are learning how to do these things. We believe that the kind of experimental program we are talking about here will, indeed, help us to do this. But it is very difficult to be specific because the very discoveries, by their nature, are things which, if you work on them, you find out. But the very fact that you are doing basic research means you are not really sure what you are going to learn.

Senator ROCKEFELLER. I appreciate, Mr. Chairman, the emphasis from this panel not only from the watching-everything-going-on-in-the-world aspect of this, but from the moral dimension of it as well, the philosophical base, the personal parts. I thank the Chair.

Senator GORTON. I thank the panel—of course, not just for this marvellous presentation this afternoon, but for the tremendous dedication and wisdom which went into its report.

We greatly appreciate it.

I think we have used up just about all of your time, Dr. Paine, have we not?

Dr. PAINE. Yes, we are going to have to go and present our report now to the head of NASA, in the ultimate sense, that is, the President.

I must say in response, Mr. Chairman, that I think all of us on the Commission, both the Commissioners and the staff, are enormously grateful to you for having given us this question and then the resources to spend a year looking at it.

I might say, because Senator Rockefeller has emphasized the financial bind, that we are very proud of the fact that we brought it in not only on time but below the budget that was allocated.

Senator GORTON. We are very pleased with that, too.

Senator ROCKEFELLER. And in color, too.

Senator GORTON. Yes. We are in your debt.

Thank you very much.

Dr. PAINE. Thank you, Mr. Chairman.

Senator GORTON. Our next witnesses will be Dr. Van Allen and Dr. Donahue.

[Pause]

Senator GORTON. The meeting will come back to order.

Dr. Van Allen, we are delighted to welcome you here and to hear from you.

STATEMENTS OF DR. JAMES A. VAN ALLEN, DEPARTMENT OF PHYSICS AND ASTRONOMY, UNIVERSITY OF IOWA, AND DR. THOMAS M. DONAHUE, CHAIRMAN, SPACE SCIENCE BOARD, NATIONAL RESEARCH COUNCIL, NATIONAL ACADEMY OF SCIENCES

Dr. VAN ALLEN. Thank you very much, Mr. Chairman.

I am very grateful for this opportunity to participate in your hearings today.

I have a short written statement which I should like to read. In addition to that, I have two other documents which I have deposited with the staff.

Senator GORTON. Fine. They will be included in the record by reference.

Dr. VAN ALLEN. Thank you very much.

Let me say that this would be a very dull afternoon if we were all to agree. So I already promise that that will not be the case.

It is courageous, perhaps even foolhardy, to go on the public record with an agenda for the next 50 years, especially in a highly technical field. For example, I have not found any anticipation of the invention of the transistor in forecasts of 50 years ago. Yet today the transistor and associated electronic techniques have revolutionized communications and computing, and have made possible numerous devices in daily use by the general public. And they are of crucial importance to sophisticated space equipment.

It is very easy to visualize ambitious projects in space. Such projects have been the stock in trade of science fiction writers for many centuries. With no difficulty whatever, I can think of a billion dollar space

project before breakfast, any day of the week, or a multibillion dollar project before breakfast on Sunday.

I might comment that my favorite project for this week is to land the first human crew on the planet Pluto and return it safely to Earth. That is somewhat beyond the scope of the commission's report.

The "Report of the National Commission on Space" contains no essentially new concepts or new material. It is, however, an excellent digest of concepts and aspirations that have been a part of our culture for many, many years.

A few examples of its worthy antecedents are: Willy Ley and Chesley Bonestell's 1951 book, "The Conquest of Space;" Wernher von Braun's 1952 book, "Das Marsprojekt;" and a series of articles by von Braun, Fred L. Whipple, and other authors in "Collier's Magazine" during 1952 to 1954.

Coming more precisely to the issue at hand today, I wish to refer to a famous Federal document entitled "The Post-Apollo Space Program: Directions for the Future—Space Task Group Report to the President," dated September, 1969.

This report was prepared in response to a directive issued by President Nixon soon after his inauguration in early 1969.

I was a member of his pre-inaugural committee on space and have a clear recollection of his reaction to our advice and of the basis for his directive.

The Space Task Group consisted of Vice President Spiro T. Agnew, as Chairman; Robert C. Seamans, Secretary of the Air Force; Thomas O. Paine, Administrator of the National Aeronautics and Space Administration; and Lee A. Dubridge, Science Advisor to the President.

I have re-read this 17 year old report recently—in fact, I have a copy with me today—and find that its substance, including budgetary projections for various options, is virtually identical to that of the 1986 report of the National Commission on Space.

The Agnew Report was delivered to the President only a few months after the first Apollo landing on the Moon in July, 1969.

Despite NASA's well-earned acclaim for this achievement, the budget of the agency was already declining rapidly at that time. The Task Force's recommendations did not reverse this trend. In fact, manned exploration of the Moon was discontinued abruptly in 1972, and the annual budget of NASA finally levelled off at about one-third of its 1964 peak, measured in normalized dollars.

This level of effort has remained essentially the same at a frozen level for the past 12 years, representing, I think, a kind of political/sociological equilibrium between advocates and skeptics of civil space activity.

In partial response to the Agnew Report, NASA proposed to develop a reusable space shuttle in order to make a drastic reduction in launching costs.

On several occasions in 1971 and 1972, I sat at this witness table in hearings of your committee, or another one just like it, and at a similar one on the House side, while representatives of NASA promised the Congress that each shuttle would carry a payload of 50,000 pounds into

low earth orbit at a launching cost of $100 per pound, that each shuttle would be good for 100 flights, and that the agency would be conducting 50 shuttle flights per year by the early 1980s.

Despite testimony by me and a few others expressing extreme skepticism of these claims, Congress did approve the program. But, in subsequent years, they failed to give it adequate support.

Partly for this reason and partly because of NASA's outrageous optimism, we find ourselves in the present state of massive disarray, frustration, and national trauma.

Against this backdrop of experience, I read the Report of the National Commission on Space with keen interest but with the overwhelming feeling of having been there before.

Moreover, the national situation in 1986 is markedly less propitious for an accelerated civilian space program than it was in 1969, on at least two grounds.

First, in contrast to the national pride in the Apollo program, we are now faced with much less public interest in the space flight of human crews—a waning interest further chilled by the *Challenger* disaster.

Second, we must anticipate stringent limits on funding for our civilian space program during the next decade as part of the effort to reduce the annually growing Federal deficit.

I would be delighted to see the United States undertake the full agenda of the National Commission on Space. But, as a pragmatist, I am totally unable to foresee anything other than a rather feeble effort in that direction during the next few years. Worse yet, President Reagan is politically committed to the costly resumption of shuttle flights, possibly including a replacement shuttle, and the even more costly development of a system of permanently manned space stations—all within a frozen NASA budget.

My own agenda for the near-term is really quite different. It recognizes the realities of our present situation and strives to revive those elements of our space program that experience has shown to be the most successful and the most important.

My agenda is as follows:

First, to suspend manned flight indefinitely, pending critical assessment of its justification. I might say that this is not a terribly radical suggestion since it is already suspended indefinitely.

Second is to postpone development of the space station.

Third is to resume the production of previously well-developed expendable launch vehicles, such as Scout, Delta, Atlas, Centaur, and Titan and upgrade their performances progressively.

Fourth is to seek lower cost launching techniques.

This, of course, is a universal desire with an unknown solution.

Fifth is to emphasize advanced applicational and scientific work.

Last is to recast the structure and the public image of NASA to those of an agency whose primary purposes are to develop space applications of widespread human importance and make major advances in human understanding of the great universe within which we are privileged to live.

But if, contrary to my expectation, Congress increases NASA's budget by 15 percent per year for the next 10 years, I will be very happy to shift my support to Dr. Paine's agenda.

Thank you, sir.

[The statement follows:]

STATEMENT OF DR. JAMES A. VAN ALLEN

Mr. Chairman and members of the committee: I am grateful for this opportunity to participate in your hearings on the future of our civilian space program.

It is courageous, perhaps even foolhardy, to go on the public record with an agenda for the next 50 years, especially in a highly technical field. For example, I have not found any anticipation of the invention of the transistor in forecasts of 50 years ago. Yet today the transistor and associated electronic techniques have revolutionized communications and computing, and have made possible numerous devices in daily use by the general public; and are of crucial importance to sophisticated space equipment.

It is easy to visualize ambitious projects in space. Such projects have been the stock in trade of science fiction writers for many centuries. With no difficulty whatever, I can think of a billion dollar space project before breakfast, any day of the week; or a two billion dollar project before breakfast on Sunday.

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Despite NASA's well earned acclaim for this achievement, the budget of the agency was already declining rapidly at that time. The Task Group's recommendations did not reverse this trend. In fact, manned exploration of the moon was discontinued abruptly in 1972 and the annual budget of NASA finally leveled off at about one-third of its 1964 peak (in normalized dollars). This level of effort has remained essentially the same for the past twelve years.

In partial response to the Agnew report, NASA proposed to develop a reusable space shuttle in order to make a drastic reduction in launching costs. On several occasions in 1971 and 1972, I sat at this witness table in hearings of your committee and at a similar one on the House side while representatives of NASA promised the Congress that each shuttle would carry a payload of 50,000 pounds into low earth orbit at a launching cost of $100 per pound and that the agency would be conducting fifty shuttle flights per year by the early 1980's. Despite testimony by myself and a few others expressing extreme skepticism of these claims, Congress did approve the program. But in subsequent years they failed to give it adequate support. Partly for this reason and partly because of NASA's outrageous optimism, we find ourselves in the present state of massive disarray and national trauma.

Against this backdrop of experience, I read the Report of the National Commission on Space with keen interest but with the overwhelming feeling of having been there before.

Moreover, the national situation in 1986 is markedly less propitious for an accelerated civilian space program than it was in 1969, on at least two grounds. First, in contrast to the national pride in the Apollo program we are now faced with much less public interest in the space flight of human crews—a waning interest further chilled by the Challenger disaster. Second, we must anticipate stringent limits on funding for our civilian space program during the next decade as part of the effort to reduce the annually growing federal deficit.

I would be delighted to see the United States undertake the full agenda of the National Commission on Space but, as a pragmatist, I am totally unable to foresee anything other than a rather feeble effort in that direction during the next few years. Worse yet, President Reagan is politically committed to the costly resumption of shuttle flights and the even more costly development of a system of permanently manned space stations—all within a frozen NASA budget.

My own agenda for the near term is quite different. It recognizes the realities of our present situation and strives to revive those elements of our space program that experience has shown to be the most successful and the most important. It is as follows:

Suspend manned flight indefinitely pending critical assessment of its justification. Postpone development of the space station. Resume the production of previously well-developed expendable launch vehicles such as Scout, Delta, Atlas, Centaur, and Titan and upgrade their performances progressively. Seek lower cost launching techniques. Emphasize advanced applicational and scientific work. Recast the structure and the public image of NASA to those of an agency whose primary purposes are to develop space applications of widespread human importance and make major advances in human understanding of the great universe within which we are privileged to live.

But if, contrary to my expectation, Congress increases NASA's budget by 15% per year for the next ten years, I will be very happy to shift my support to Dr. Payne's agenda.

Senator GORTON. Thank you.

Dr. DONAHUE. Thank you, Mr. Chairman and Senator Rockefeller for asking me to come here this afternoon to comment on the "Report of the National Commission on Space."

As you know, I am Chairman of the Space Science Board of the National Research Council, and, as such, I represent an organization whose special competence is in science.

So I shall confine my remarks to scientific matters, and that makes my task very simple.

We and the commission share a common perception of the goals of science, the goals that science should seek to attain during the first couple of decades of the twenty-first century.

It is not difficult, therefore, for me to endorse enthusiastically that part of the report that deals with science.

The commission identifies as the first of its major thrusts that it proposes for the civilian space program, the space agenda, as "advancing our understanding of our planet, our solar system, and the universe," and it recommends a supporting commitment by the nation to advance "technology across a broad spectrum" to assure timely availability of critical resources.

The Space Science Board fully supports these recommendations.

Furthermore, the recommendations in the section of the report that is entitled "Advancing Science' are based on the need to answer a list of questions that, as the commission said, was provided to it by the Space Science Board. Furthermore, the Board is just completing a 2-year study entitled "Space Science in the Twenty-first Century: Imperatives for Two Decades, From 1995 to 2015," which was undertaken at the request of NASA.

Jim Van Allen, here, and George Field, who is still in the audience, participated in that study, and, as the report states, the preliminary findings and recommendations from that study were used in plotting the course for space science beyond 1995 in the commission's report.

So it is not difficult to see why the recommendations in the report for a global study of planet Earth or fundamental biology, physics, and chemistry in Earth orbit or human biology in space, or in space physics, astronomy and astrophysics, and a study of the solar system are so similar to those that the Board itself is preparing to make.

You have also asked me to comment on the compatibility of the recommendations in the commission's report with national resources that may be available.

Well, if you keep in mind that the space program, during the days of Apollo, was run at three times the budgetary level to which it has been held during the past decade, I do not see any reason why the Nation cannot afford the kind of space science activity which is recommended by the commission for the first two decades of the next century.

I am not going to comment on the rest of the commission's recommendations, partly because I am here representing the Space Science Board. The decision on accepting them is not one that will be based on the scientific aspect of the report, that is, the decision on accepting the entire package.

Most scientists strongly believe that the advance of science and its applications to human welfare would provide a worthy key objective of the space program of the United States in that scientific objectives can provide any degree of challenge in the development of space technology and thus assure that scientific and engineering resources are effectively utilized in the national interest.

The scientific program in the report, "Pioneering the Space Frontier," is one that would meet those requirements.

I must confess that I am much more preoccupied by short-range concerns, as I sense so many of us are here, than with the subject you asked me to come here to address, and that is the concern of how to fix the present space program, which has been "broken" since the early 1970s, as Jim Van Allen has just pointed out, the situation that culminated in the *Challenger* accident. The problem for science and the problem for all users of the space program is acquiring access to space, and that is something that we do not have now because of the inadequacy of the shuttle to provide that means of access.

In my prepared statement, I have made specific recommendations at some length, that I would be prepared to go over with you in detail, whenever you wish.

Thank you, Senators.

[The statement follows:]

STATEMENT OF DR. THOMAS M. DONAHUE, CHAIRMAN, SPACE SCIENCE BOARD, NATIONAL RESEARCH COUNCIL, NATIONAL ACADEMY OF SCIENCES

Mr. Chairman, Members of the Subcommittee, Ladies and Gentlemen:

Thank you for asking me to come here this afternoon to discuss the report of the National Commission on Space and other important matters relating to the nation's space program. As you know I am Chairman of the Space Science Board and as such represent an organization whose special competence is in science.

Hence in my testimony regarding the Commission's report I shall confine my remarks to scientific matters. This makes my task very simple. It is not difficult for me to endorse enthusiastically that part of the report that deals with science. The Commission identifies as the first of the major thrusts that it proposes for the civilian space agenda as "Advancing our understanding of our planet, our Solar System and the Universe" and it recommends a supporting commitment by the nation to advance "technology across a broad spectrum to assure timely availability of critical capabilities". The Space Science Board fully supports these recommendations. Furthermore, the recommendations in the section of the report entitled "Advancing Science"—from page 25 through page 57 in the report—are based on the need to answer a list of questions provided to the Commission, as they acknowledge, by the Space Science Board. The Space Science Board is just completing a two-year study entitled "Space Science in the Twenty-First Century, Imperatives for Two Decades (1995–2015)", undertaken at the request of NASA. Professor George Field participated in our study and was also a member of the Commission. As the report states, preliminary findings and recommendations from our study were used in plotting the course for space science beyond 1995 in the Commission's report. It is, therefore, not difficult to see why the recommendations in the report—for a Global Study of Planet Earth, of Fundamental Biology, Physics and Chemistry in Earth Orbit, of Human Biology in Space, Solar and Space Physics, Study of the Solar System, and Astronomy and Astrophysics—are so similar to those the Board itself is preparing to make.

Keeping in mind that the space program during days of Apollo was run at three times the budgetary level to which it has been held during the past decade, I see no reason why the nation cannot afford the kind of space science activity recommended by the Commission during the first two decades of the next century. I am not prepared to comment about the rest of the Commission's recommendations. The decision on accepting them is not one that will be based on the scientific aspect of the report. There are many reasons that mankind is in space. Most scientists believe strongly that the advance of science and its applications to human welfare would provide a worthy key objective of the space program of the United States and that scientific objectives can provide any desired degree of challenge in the development of space technology, thus assuring that scientific and engineering resources are effectively utilized in the national interest, as required by the National Aeronautics and Space Act of 1958. The scientific program in the report, "Pioneering the Space Frontier", is one that would meet these requirements.

Let me turn now to the crisis the nation is facing today in its space program. In our opinion, the Challenger accident has revealed that the space program the United States has been following since the days of Apollo has a number of fundamental structural flaws that must be corrected. Recently, the Space Science Board released a position paper dealing with some of these problems, entitled "The Nation's Space Program After Challenger: The Need for a Reassessment of the Roles of Manned and Unmanned Systems for Launching Scientific Space Missions". A copy is included as a part of my testimony here today. That paper asserts that it is not appropriate to use the space shuttle as a platform to launch spacecraft. It asserts that to try to do so mixes the objectives of the manned and unmanned elements of the space program in ways that reduce the effectiveness of both of them—thereby threatening our scientific and technological leadership in space. It calls for a drastic change in policy that would correct the mistaken policy of relying on the shuttle as our only means of launching scientific missions and once again make Expendable Launch Vehicles (ELVs) the primary system for launching scientific spacecraft.

Events that have occurred since we issued our position paper on May 21 have only served to reinforce the position we took then. Of these the most dramatic was the decision to cancel the Shuttle Centaur G' program. The lengthening of the shuttle standdown from 18 months to at least two years is another. If we depend on the shuttle to launch Galileo, Ulysses and Magellan the launch window that exists in the last quarter of 1989 for these missions would close, and we would have to contemplate launches in January 1991, October 1990 and June 1991, respectively for these three missions. Further, it is my understanding that the issue of using shuttle

for Galileo and perhaps Ulysses may be academic anyway because of Shuttle landing weight constraints. If Galileo should be launched in 1991 on a "delta VEGA" trajectory it would arrive at Jupiter in the middle of 1995. Remember that Galileo was once supposed to get to Jupiter this year. I can easily evaluate the impact this 9 year delay will have on the scientific community because I am a scientific co-investigator on Galileo. Instead of looking at data this year when I am reasonably alert at the age of 65, I have to contemplate trying to hold out until I am 74 before I begin to analyze those results. Sometimes it takes me two or three years to realize the significance of data I have obtained from an experiment so I may be getting on toward 80 before I get some of the best analysis published. Fortunately for me Pioneer Venus and Voyager are still working and I am involved with both of them. Many of my colleagues are not that lucky. I must tell you most bluntly that delays of the sort that we are facing are absolutely devastating for space scientists in all disciplines, whether they depend on free flyers or shuttle-attached payloads. A grey beard like me has at least enjoyed the golden years of space science in the 50's, the 60's and the 70's. But my young colleagues who are students, or young professionals, would be poorly advised now to try to stick with space science as a career unless we do something to prevent this disaster from engulfing them.

In fact all scientific spacecraft that are now approved, with the exception of the Hubble Space Telescope, are compatible with Expendable Launch Vehicles. The Titan 34D7—Centaur G' combination can accommodate our most demanding requirements. Atlas Centaurs and Deltas are adequate for other missions. I challenge the assertion that NASA cannot procure Titan CELVs (complementary ELVs) by the fall of 1989 in order to launch the three planetary missions I have mentioned and the Gamma Ray Observatory and the Mars Observer mission in a timely fashion. I urge you to do whatever you can to reset our space science program on a sound course by supporting the policy of using ELVs to launch scientific space missions.

The Challenger accident and the Rogers Commission investigation should have convinced us that the shuttle is still in a developmental stage and that it is not now possible to predict when it will become a safe, reliable operational system. Until sound risk analysis estimates give assurance that the chances of a serious accident have changed by orders of magnitude from one in twenty five—and not just by factors 2 or 5—we should treat each shuttle launch as a test and not declare that the shuttle has reached the operational stage or plan to use it systematically as part of a spacecraft launch system.

But even after it has proven itself to be reliable it will make little sense to use the shuttle to launch spacecraft. Shuttle crews should be used to perform tasks in space for which people are needed or where their intervention is truly useful and not just to ride along on what amounts to the first stage of a launch vehicle. There are many activities astronauts can perform in life science experiments, for example, that are very exciting. I certainly don't argue against using the shuttle for scientific missions such as those in life sciences or those in which free flyers are serviced or retrieved. But there are so many limitations that must be imposed when the shuttle is used to get spacecraft to low earth orbit, such as limitations having to do with weather, onboard safety, and landing weight, that the shuttle is just not acceptable as a launch vehicle. As an example it now appears that it may be necessary to eliminate a very important experiment that happens to vent hydrogen gas from the Upper Atmosphere Research Satellite (UARS), if it is to be launched from the shuttle. If the purpose of the shuttle is not just to get people up to low earth orbit and back to earth safely, then compromises with safety will have to be tolerated or a substitute found for certain uses of the shuttle.

The question of how to pay for ELVs will naturally arise. If it is necessary to find funds within a fixed NASA budget for this purpose at the expense of other programs I, as a scientist, would not hesitate to identify lower priority activities from which they could be drawn. Postponing procurement of the replacement orbiter and/or descoping and delaying the space station would be two of them. The acquisition of ELVs to assure access to space for science missions ranks in scientific priority above both of these activities. It would make little sense to me to continue apace these large technical endeavors at the expense of a program which is intended to be one, if not the primary, user of the facilities.

It seems obvious to me that the fundamental problems with our space program will not be solved if we just decide to procure a replacement for Challenger and continue to acquire the presently proposed initial operational capability of the space station for the mid-1990's and start work on the space plane, even if all of that can be done without cutting other programs, such as space science and applications. This procedure would just get us back where we were before January 27 with a pro-

gram that is a proven failure, because it does not assure access to space to the only real users of space. Our first priority should be to obtain that assurance and that means to give precedence to the acquisition of alternatives to the shuttle. It also may mean changing the way this nation goes about doing things in space—by making huge technological quantum leaps. The only large scale space program that is working very well these days is the Soviet one. It has gotten where it is by a process of improving reliable technological systems, particularly launch vehicles and space stations, in relatively small increments. The tortoise seems to be winning the race with the hare again.

The present standdown is threatening to cause an average delay to space science and applications free flyers of about three and a half years and to attached payloads of about four and one-half years. As we all know these delays cost huge amounts of money for which we get no return in the way of scientific data. If space science is tc survive these four years in the desert, ways must be found to keep scientists working on scientific space projects. Obviously existing spacecraft in orbit must be kept operating and investigations using data from them must be kept fully funded—unless it is demonstrable that the returns are not worth the effort. Suborbital programs and especially the Explorer program should be greatly expanded and extended to all disciplines of space science at once. I am thinking in terms of factors of three or so increase. The level of research and analysis programs must be augmented. There is an emergency. The nation must respond to it or lose the base for the science programs of the future. For much the same reasons it is important that we continue to make progress toward flight projects of the future. Some way of going ahead with big programs such as ISTP, AXAF, CRAF needs to be developed.

Looking ahead to the time when shuttle flights are resumed, it is also clear that a way must be found to insure access for space science and applications payloads to the shuttle along with national security payloads. Obviously serious national security needs must be accommodated first, but a firm arrangement to allocate some fraction—say one-third—of all shuttle flights to science and applications is reasonable and even mandatory.

I hope that what I have had to say does not seem unduly self-serving. My assignment is to inform you about the needs of space science. It is up to you to decide whether space science is worth preserving. I know that you gentlemen care as much about the space program as I do. I hope that we can join in calling on the nation to rededicate itself to a strong, exciting effort in space that will restore us to our accustomed place of leadership.

Senator GORTON. Thank you.

Dr. Van Allen, when you were appearing before the predecessors of this committee in 1971 and 1972, what were your recomendations for the future of the space program, for the space shuttle at that time?

Dr. VAN ALLEN. My basic position at that time was that we had a well developed stable of expendable launch vehicles—they are essentially the same list we have today—and that those were well developed and relatively inexpensive, in my judgment, compared to what the shuttle would cost, and had a level of reliability which would give us a diverse and resilient launching capability.

I also expressed very grave skepticism about the claims that were then being made by NASA about the cost of launching with a shuttle.

Senator GORTON. I take it your recommendations were simply to go on with what we were already doing with incremental improvements?

Dr. VAN ALLEN. Basically, yes.

Senator GORTON. Did that include or not include any kind of emphasis on manned space flight?

Dr. VAN ALLEN. I didn't catch your last words, sir.

Senator GORTON. Did that include or not include further manned space flight, or were you dealing exclusively with ELVs?

Dr. VAN ALLEN. I did not take a position on that either way. I have not been one of the well-known advocates of manned flight as a component of our national program. On the other hand, I have never been against it, either. I think we have to size it up pragmatically. That was the position I took at that time.

Senator GORTON. Is it your view that had we followed those recommendations in 1971 and 1972, we would be spending the same amount of money today on space that we are?

Dr. VAN ALLEN. Well, we could be. Of course, the amount that we spend is in some sense arbitrary. It is determined by your committee, among others.

I think it depends on the interplay between the advocates and the skeptics concerning what is worthwhile to do in space.

My judgment is that we have reached a kind of equilibrium of that sort. It is represented by essentially a constant budgetary level for the last 12 or 13 years. It has been almost dead flat in terms of real purchasing power or human effort.

I think the mix would have been different—let me put it that way, Senator. We would have had a much greater, more vigorous applicational and scientific program and less emphasis on the manned area.

Senator GORTON. Of course, I was not a member of this body or this committee at the time. But I am inclined to feel fairly strongly, however, that had we followed that course of action, we would not have had a steady appropriation for NASA in constant dollars, either in real dollars or in nominal dollars, but almost certainly a constantly lessening of appropriations.

I guess one of the great difficulties that we have to face is whether or not the amount of money that we can find here in the Congress drives the program or whether the dreams and desires of the program to a certain extent drive how much money we can get for it. And unless we have something which tends to both keep the interest of the American people, and to the extent that we can stretch their imaginations, I do not think we would continue to spend what we are now.

Dr. VAN ALLEN. Well, I realize that that is a question to which the answer is not known, and I have given various reasons for thinking the contrary in articles that I have written recently. It is certainly not a theorem that that is the case.

Senator GORTON. True.

Dr. VAN ALLEN. It is a judgment call which very well could be wrong.

I think that if the American people properly understood what space is really good for, there would be ample support for something like the present level of effort.

I am thinking about applications in weather, navigation, geodesy, oceanography, communications of all sorts. If all of these things were brought to the public attention properly and honestly, I think they would have ample support.

Senator GORTON. On the other hand, you did say at the very end of your testimony that you felt if we could have a 15 percent increase in space support for a year for a considerable period of time, then you would find yourself in agreement with the recommendations of this commission, which you pointed out were remarkably similar to recommendations made almost two decades ago.

I take it, therefore, that the fact that the recommendations of this commission are quite similar to those in 1969 is not a critique either of 1969 or 1986 in one sense, but a validation of both?

Dr. VAN ALLEN. Well, of course, there is a good deal of commonality of thinking.

For example, Dr. Paine was a member of both groups and Chairman of the present one. That gives one the expectation that there is some commonality of thinking.

The things that the commission has enunciated in terms of long-term goals are part of our culture. There is nothing original to the commission's report. I hope I made that clear. I can cite any number of previously published books by well-known futurists who have all these same concepts in them. It is a kind of digest under an official umbrella.

So I do not think they are necessarily either validated or invalidated by being repeated. They are repeated every day, actually, in various contexts.

Senator GORTON. I would like both of you to comment on my next question.

Can either of you give us any help or any insignt into what it would take to make the climate of public opinion in the United States more propitious for implementing the recommendations of this commission or, in any event, toward supporting a more ambitious space program than it appears we will be able to fund in the course of the next few years.

Dr. VAN ALLEN. I will try that one and I think Tom ought to have a crack at that one, too, Mr. Chairman.

It may be impossible. I think that is one answer. It might be a kind of practical answer.

I think we can sustain something like the present effort but make it much more fruitful. That is essentially my judgment of the total situation.

We can sustain an effort of this general magnitude and the American people, if properly informed, will endorse it at something like this level.

Now, the present cost of NASA's program is about $30 per year per capita. That sounds like a pretty small amount of money. But for the head of a family, it is $120. If we were to increase that three to four times, which is essentially what is proposed by the commission, we are up to $400 or $500 per family.

Again, that may or may not be judged worthwhile by the average head of a family, but I think he begins to have very grave doubts about it at that level.

Senator GORTON. Thank you.

Dr. Donahue.

Dr. DONAHUE. I tend to challenge a little bit the basis of your statement, that there is as much resistance to this program, to the space program, or lack of enthusiasm for the space program out there, as some of us perceive.

I find, as I go out and talk to the people, that they are intrigued, they are supportive of the space program.

I do not think we have as much of a problem as sometimes we believe that we do.

We have a grave problem right now because the space program is perceived as floudering, and that is an image that is difficult to erase. It is difficult to try to sell something positive in that climate. So I see our problem right now as to fix the space program, and once it is working again, I believe the American people would enthuse about even the sort of thing that the Paine Commission is recommending.

Senator GORTON. Dr. Donahue, I believe your written statement leaves the impression that you feel that one of the competing technologies for the next generation vehicle, the aerospace plane, is of questionable value.

Is that a fair implication from what you say in your written statement?

Will you comment on that in general terms.

Dr. DONAHUE. If I said something like that, I think it was in the context of priorities. My judgment is that the most important problem we face right now is getting a means of launching payloads and getting them back into orbit.

To me that says that the first priority is acquisition of expendible launch vehicles, and this means acquisition of expendible launch vehicles, such as the seven segment Titan Centaur, to launch the three major science missions that need to be launched at the end of 1989.

Now, to pay for those, if it is necessary to give up something else, I would postpone acquisition of the replacement orbiter. I would slow down or descope the space station, and I would reduce the level of activity in acquiring that plane.

I think the question of the feasibility of that plane is one that is so much in doubt right now that it is very difficult to pass a judgment on the thing. The question is whether the motor works or not.

Now much more important than getting going on that thing is finding a way to get Galileo, to get Ulysses, to get Magellan, to get the Gamma Ray Observatory—all of those missions that are already built or being built—into orbit. I do not think the shuttle is ever going to be a suitable way of launching those space craft. The only way to do it, in my opinion, is to use expendible launch vehicles. Hence that is my first priority.

Senator GORTON. I take it you would agree with that statement?

Dr. VAN ALLEN. Yes, very much, Mr. Chairman. I would add to what Tom just said that the United States has several billion dollars worth of high priority payloads in the launching queue at the present time, and

those consist of a comprehensive mix of commercial military, application of and scientific payloads.

So I join with Dr. Donahue in the feeling that the real national emergency at this point in time is to regain our launching capability. There is nothing in my judgment that competes with that at the present time as a national urgency.

Senator GORTON. Both of you of course know that the commission suggested the establishment of a White House National and Aeronautics Space Council. I would like your comments on that, whether or not you think it is particularly important or not much more than window dressing, and if you think it is potentially important, how ought it to be composed?

Dr. VAN ALLEN. I am more or less familiar with how that operated in the early days. The Vice President was the Ex-Officio Chairman of the National Space Council, and there were a number of other persons designated by law. I cannot remember the exact list, but I think it included the Secretary of Defense, the Administrator of NASA and the Secretary of State. In my judgment, it was constituted at such a high level that no one ever did anything in a cognitive sense. I think it was definitely in the "window dressing" department, although they did develop a small, but good, staff over the years which came and went and made some significant studies.

But it was in no sense effective as a board of directors of an enterprise.

Senator GORTON. Dr. Donahue?

Dr. DONAHUE. I agree with Van in his characterization of the old Council. But somethign of that sort, something like a board of directors, might be useful to the National Space Board, for example.

We need something that really would function as a board of directors and not be at quite such a high level.

I am certainly not an enthusiastic fan of the present collection of people who worry about these issues, that is the Senior Inter-Agency Group on Space. That does not seem to me like the right way to run a space agency.

Senator GORTON. It doesn't to me, either.

Gentlemen, we have kept you a long time this afternoon yet, your testimony has been of considerable help to the subcommittee.

We really do appreciate your coming.

Dr. Van Allen, it was not only good for us but refreshing for us to get a different point of view.

Dr. Van Allen. Thank you very much, Mr. Chairman.

Dr. DONAHUE. Thank you.

Senator GORTON. Thank you, both.

[Whereupon, at 4:35 p.m., the subcommittee adjourned, to reconvene upon the call of the Chair.]

[The following information was subsequently received for the record:]

THE NATION'S SPACE PROGRAM AFTER CHALLENGER: THE NEED FOR A REASSESSMENT OF THE ROLES OF MANNED AND UNMANNED SYSTEMS FOR LAUNCHING SCIENTIFIC SPACE MISSIONS

The Space Science Board of the National Research Council shares with NASA and the Nation a deep sense of grief over the loss of the crew of the space shuttle Challenger—seven exceptional Americans whose lives were dedicated to some of our country's loftiest goals.

At this time of national reflection following the tragedy, much thoughtful consideration is being given to the goals and the future of the American space program. We believe that these reflections on our country's efforts in space are very appropriate. *In the course of these considerations we urge that high priority be given to assessing the proper level of resources required for the nation's space program and the proper balance between manned and unmanned activities. This reexamination should assign to manned and unmanned systems and launch vehicles the roles that will permit each to serve the nation best, in contrast to the course we have been following for the past fifteen years.* The result of this analysis may call for the allocation of greater resources than we are presently devoting to the space program. It may call for better management of those resources or a mixture of both. In any case, we also believe that it is mandatory to ask whether this nation should proceed with such a highly visible, prestigious national enterprise on the frontiers of technology at an effective level of resources where the consequences of a single tragic accident can cripple the entire program, civilian and military. It is now time to determine the strength of the national will for our country's space effort, and to determine if it is our intent to pursue a pioneering program on the frontiers of space embracing a wide range of activities. If the nation concludes, as we believe it should, that such a course is in the national interest, then it should resolve to devote to that effort the means to carry it out properly.

Since 1974 the annual budget for the civilian space program has remained almost constant at about $7.5 billion, corrected for inflation to 1986 dollars. In contrast, the peak funding level in the mid 1960s—in the midst of the Apollo program—was three times as large. This substantial reduction in our space effort reflects a decision that was made at the conclusion of the Apollo program not to provide the means to undertake soon another ambitious, challenging space program similar to the one that had placed men on the Moon and returned them to Earth. Furthermore, following Apollo the nation failed to identify any clear goals for its space program, but, nevertheless, tried to attain a level of activity well above the limit set by the means that have effectively been available.

The major new program in manned space flight that was authorized during the decade of the seventies was the space shuttle, a transportation system that was meant to be the sole national means of access to space and was expected ultimately to be economically self-sustaining. Later, related actions stopped the procurement of expendable launch vehicles before the shuttle became a proven, reliable system; prevented planning for the development of advanced unmanned launch systems; and encouraged planning for two ambitious scientific missions, Galileo and Ulysses, to use the shuttle in a manner that would severely test its capability in the first attempts to launch high priority science spacecraft. These decisions had the effect of making unmanned space missions, including those of space science, dependent on manned vehicles, the shuttle in particular, in a way that caused serious problems for both aspects of the space program. This policy, which has deprived the nation of launch vehicles for major scientific payloads for almost a decade, has been devastating for space science.

The most recent launches of major science payloads requiring launch systems of the Titan-Centaur class occurred in 1977 when the two Voyager spacecraft were sent off toward the outer solar system. In the mid 1960s, scientific missions were being launched at a rate of 5 to 6 per year by the United States. A measure of the level of activity and reliability of the U.S. program before 1980 is that 9 interplanetary missions that were launched during that period are still sending valuable data from space. The Challenger accident means that at least a full decade will have lapsed between the launching of the Voyagers and the next major scientific mission by the United States. Seven full scale scientific missions have been or are being prepared for launches that were scheduled to occur during the next two years. Several others were waiting in line behind these. In the meanwhile other nations have been methodically picking up the pace and improving the quality of their scientific enterprises in space.

As a matter of highest priority in a reenergized national space program to which a realistic level of support is dedicated, we strongly urge that the nation move rapidly

toward the acquisition of a balanced fleet of launch vehicles that will provide assured access to space for all activities demanded by our national space program. The characteristics of these launch vehicles should be determined by the needs and requirements of all potential users—military, commercial, and space science. We recommend that space transportation and launch systems be expeditiously acquired that will allow human resources to be used were they are needed and can be most effective and allow unmanned vehicles to be the carrier of choice for other missions. A policy that merely provides for the use of existing commercial expendable launch vehicles would not be an adequate response to this recommendation.

In summary, it is our view that one of the most important lessons from the Challenger accident is that the objectives of a highly visible and important national endeavor such as our space program must be clearly stated, that an adequate variety and level of resources should be provided to carry out this program successfully, and that measures be taken to insure that those resources are efficiently managed. These resources should assure access to space to all elements in the space program: civilian and military, manned and unmanned. *The objectives of the manned and unmanned elements of the program should not be mixed in ways that reduce the effectiveness of either of them. To do so risks forfeiture of our scientific and technological leadership in space.*

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